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AIRCRAFT LITTER RETENTION SYSTEM DESIGN CRITERIA

By

Langston W. T. Weinberg

April 1966

U. S. ARMY AVIATION MATERIEL LABORATORIES
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Conclusions and recommendations contained in this report are concurred in by this command. The report has been reviewed, and is concurred in, by the Office of the Surgeon General.

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April 1966

AIRCRAFT LITTER RETENTION SYSTEM DESIGN CRITERIA

Technical Report
AvSER 65-13

by
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SUMMARY

Strength requirements of U. S. Army litter/patient retention systems as set forth in current military specifications were analyzed. The analysis was made in light of U. S. Army aircraft accident experience, the human tolerance to abrupt accelerations, and the forces and accelerations that may be anticipated in accidents involving litter-bearing military aircraft. The analysis revealed that the strength requirements quoted in current military specifications are considerably lower than (1) the upper limits of acceleration that can be tolerated by airborne litter occupants and (2) the typical forces and accelerations that are incurred in military aircraft accidents.

These conclusions indicated that current litter systems would fail under relatively moderate impact conditions and would thus subject the litter patient to amplified accelerations and increased contact injuries.

The existing litter system was analyzed in detail to determine if minor modifications could be made to achieve a vertical load-carrying capability of 20G. Since this strength was not attainable, an experimental litter system designed for a 20G vertical and 25G longitudinal capability was developed.

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SYMBOLS

H	maximum airframe acceleration - G
$K = \frac{a_L}{H}$	ratio of limit acceleration to peak acceleration
t_o	one-half the input pulse duration - sec
t	time - sec
$a_L = KH$	maximum litter acceleration - G
t_L	time at which the maximum litter acceleration is first reached - sec
$V(t)$	velocity of the airframe at time "t" - ft/sec
V	velocity - ft/sec
V_o	initial impact velocity - ft/sec
V_L	common velocity of airframe and litter when the maximum acceleration of the litter is first reached - ft/sec
g	acceleration due to gravity - 386 in. /sec^2
$G = \frac{a}{g}$	the ratio of any acceleration to the acceleration of gravity
$a(t)$	acceleration of the airframe at time "t" - ft/sec^2
S	displacement - ft
A	area - sq in.
a	acceleration

AIRCRAFT LITTER RETENTION SYSTEM DESIGN CRITERIA

OBJECTIVE

The objective of this study was to develop realistic design criteria for aircraft litter and litter retention systems.

BACKGROUND

Detailed examination of litter occupant mechanical restraining devices has been made (Reference 1). However, very little work had been done with reference to a complete litter retention system, including the tie-down chain from litter to retention attachment to airframe.

In 1962, Aviation Safety Engineering and Research (AvSER) conducted a full-scale dynamic crash test of a CH-21 helicopter containing a standard H-21 aircraft litter installation. This test (see Reference 2) indicated that existing military specifications pertaining to aircraft litter retention systems did not require sufficient strength to provide protection for the occupants during potentially survivable accidents. The report recommended that:

1. A thorough investigation be initiated to develop realistic design criteria for aircraft litter systems.
2. Additional testing of aircraft litter systems be made with the entire assembly instead of single components as had been done in the past.
3. Both static and dynamic tests be conducted on the litter system.
4. Dynamic tests be conducted at acceleration and energy levels consistent with impact conditions that could be expected in severe but potentially survivable accidents.

In April 1963, an additional dynamic crash test was conducted by AvSER utilizing another CH-21 helicopter. Among the many experiments that were included were two UH-1D litter systems. The cabin interior was modified to simulate the UH-1D interior, and the litter systems were installed as they would be installed in a UH-1D. One of the litter systems was installed in its standard configuration, and the other was installed with modified brackets to hold the litter in place. These special brackets were added to increase the longitudinal retention

capability over that associated with the use of standard friction-type brackets and to allow the fitting to follow the bending of the litter pole. The results of the tests on these two litter systems supported the conclusion that the strength requirements of existing military specifications are inconsistent with the actual loads imposed in survivable accident situations. Additional conclusions drawn from this series of dynamic tests that would be pertinent to future litter system development were:

1. The normal installation of litters in helicopters includes a combination of attachments to the litters; for example, 2 straps on one side and rigid wall mounts on the other. The different response characteristics of the mounting attachments cause eccentric loading on the litter itself which could cause failure at loads significantly below the actual capabilities of the system. This could be improved if all litter retention attachments were the same.

2. The standard friction-type gripping arrangement was not adequate to prevent longitudinal movement of the litter poles when even moderate loads were imposed.

From this series of dynamic crash tests with helicopters, it became apparent that the problem of litter retention in U. S. Army aeromedical evacuation aircraft would have to be reexamined in detail. Existing systems built to the requirements of MIL-A-8865(ASG) did not provide the retention characteristics needed for the loads incurred in a typical crash environment where the occupiable portion of the fuselage was left substantially intact. It was further apparent that each component of the standard litter systems would have to be analyzed with a view toward redesign.

It was in the context of this backgound that the study contained herein was conducted.

ANALYSIS OF SPECIFICATION REQUIREMENTS

The specification, MIL-A-8865(ASG), requires that supports and attachment fittings for litters be designed so that the following load factors acting separately shall apply to a 250-pound litter load:

Forward	8.0G
Lateral	1.5G
Vertical	4.5G down, 2.0G up

The specifications require only single-axis testing of the individual components. This type of testing does not consider the combined forces that are characteristic of dynamic situations. The presence of combined forces may allow failure of the components at load values equal to or below the design load factors cited above. Figure 1 depicts a standard litter system installed in a CH-21 helicopter for test purposes.

Figure 1. Standard CH-21 Litter System.

The results of an actual crash test of the litter system in Figure 1 are shown in the kinematic drawing, Figure 3. A description of the conditions that existed in the full-scale dynamic crash test (which included this litter system) is given in Reference 2. The results of the test of a standard UH-1D litter system installed in a modified CH-21 are described in Appendix I.

Figure 2 depicts a standard UH-1D litter system that has been modified to include experimental attachment fittings. These fittings, shown in Figure 4, were intended to provide increased litter retention during the high vertical and longitudinal forces known to occur in aircraft accidents.

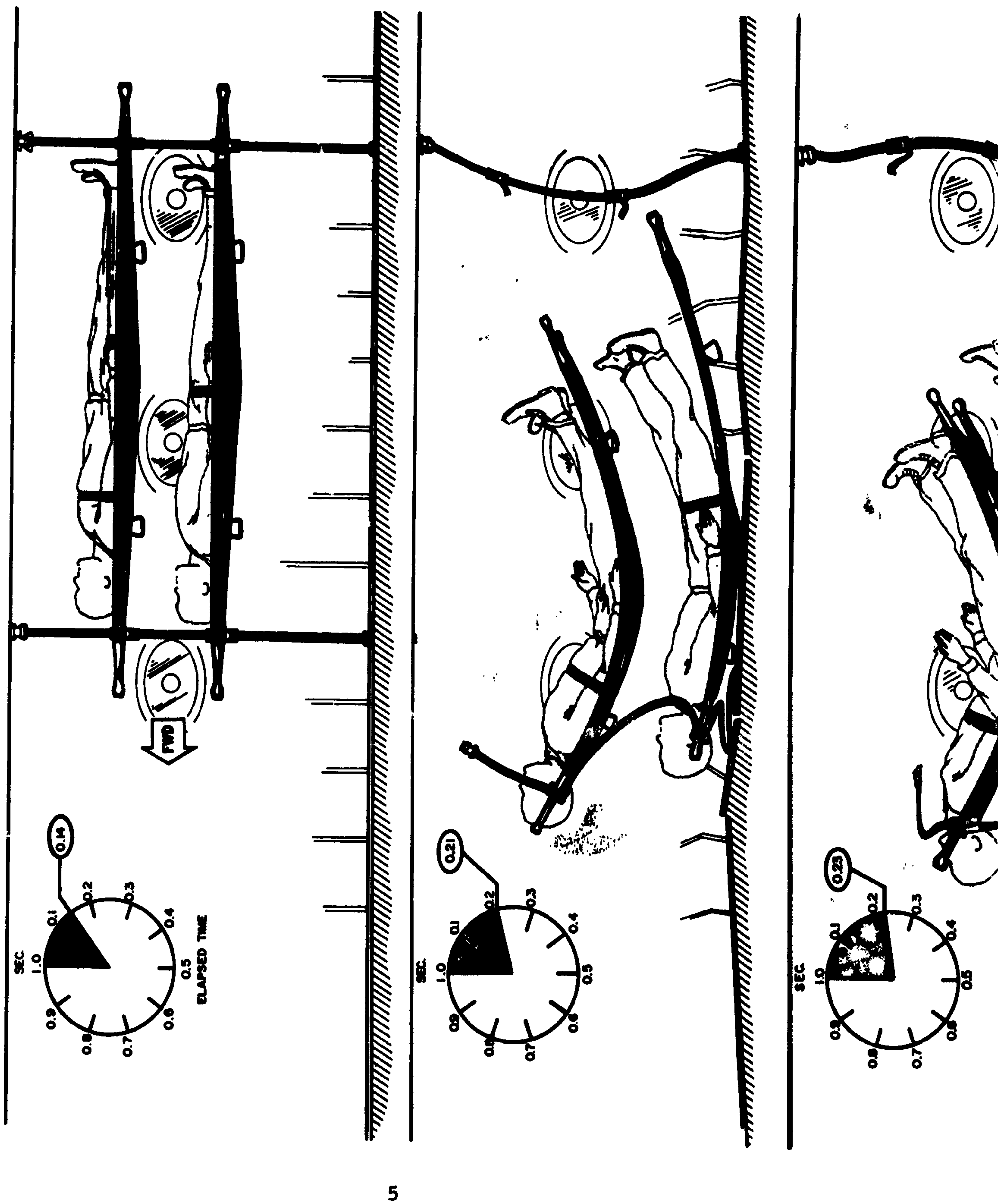
Figure 5 shows this sytem after having undergone a full-scale crash test. It was apparent after this litter test that the experimental fittings were still not satisfactory.

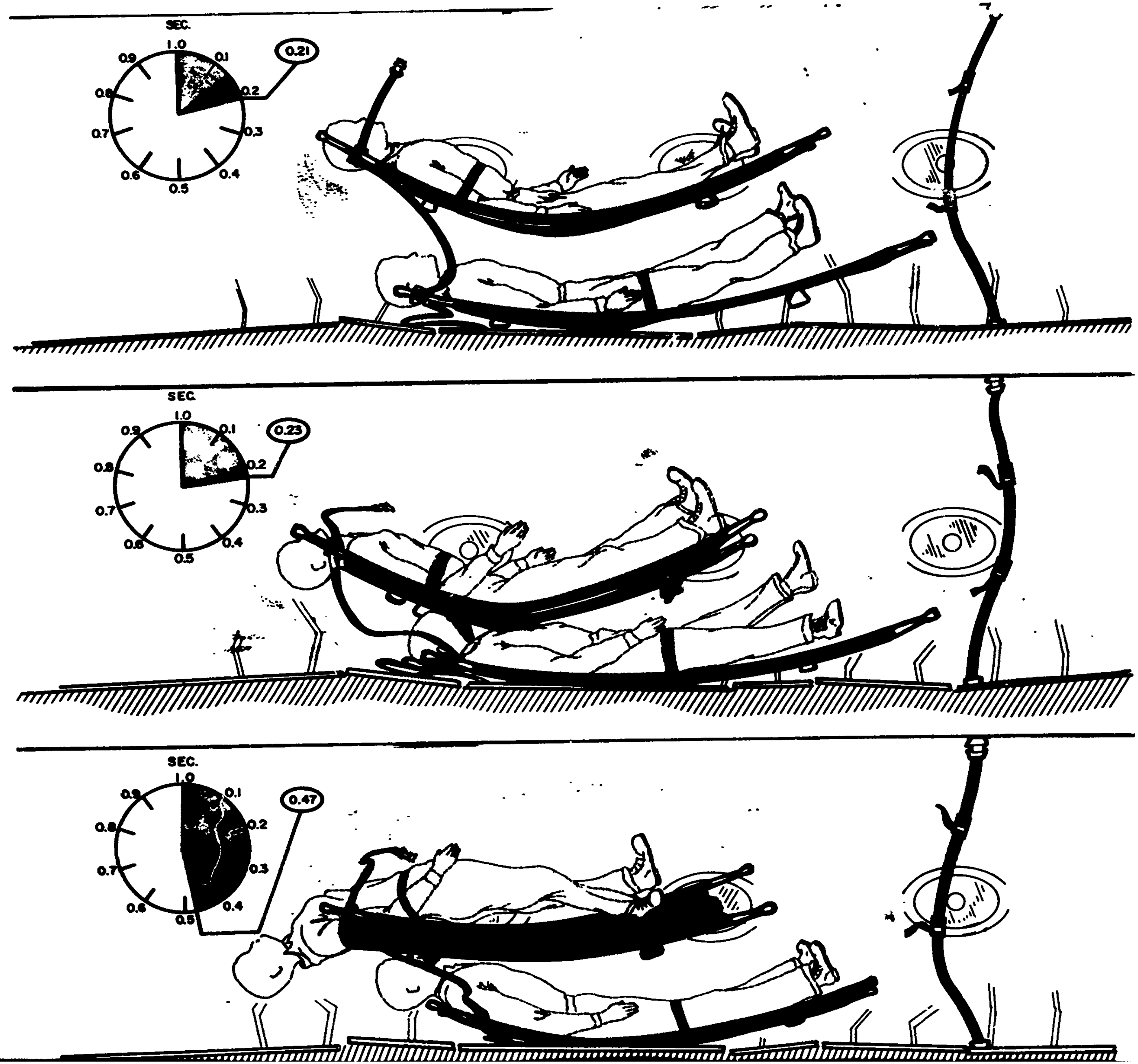
Figure 2. Standard UH-1D Litter System (Modified).

HUMAN TOLERANCE TO IMPACT ACCELERATION

Impact acceleration is generally described as a linear acceleration where the time of application is 0.20 second or less. Such an acceleration is mainly associated with ballistic catapult ejections, parachute opening shocks, and aircraft accidents; the short duration restricts their effects to mechanical overloading (skeletal and soft tissue stresses). Fluid shift disturbances or hydrostatic effects are not apparent at such short durations (Reference 3).

According to a comprehensive review of the literature by Eiband (Reference 4), the human tolerance to impact acceleration is governed by:


FWD
0.14
SEC.
ELAPSED TIME
0.21
0.25



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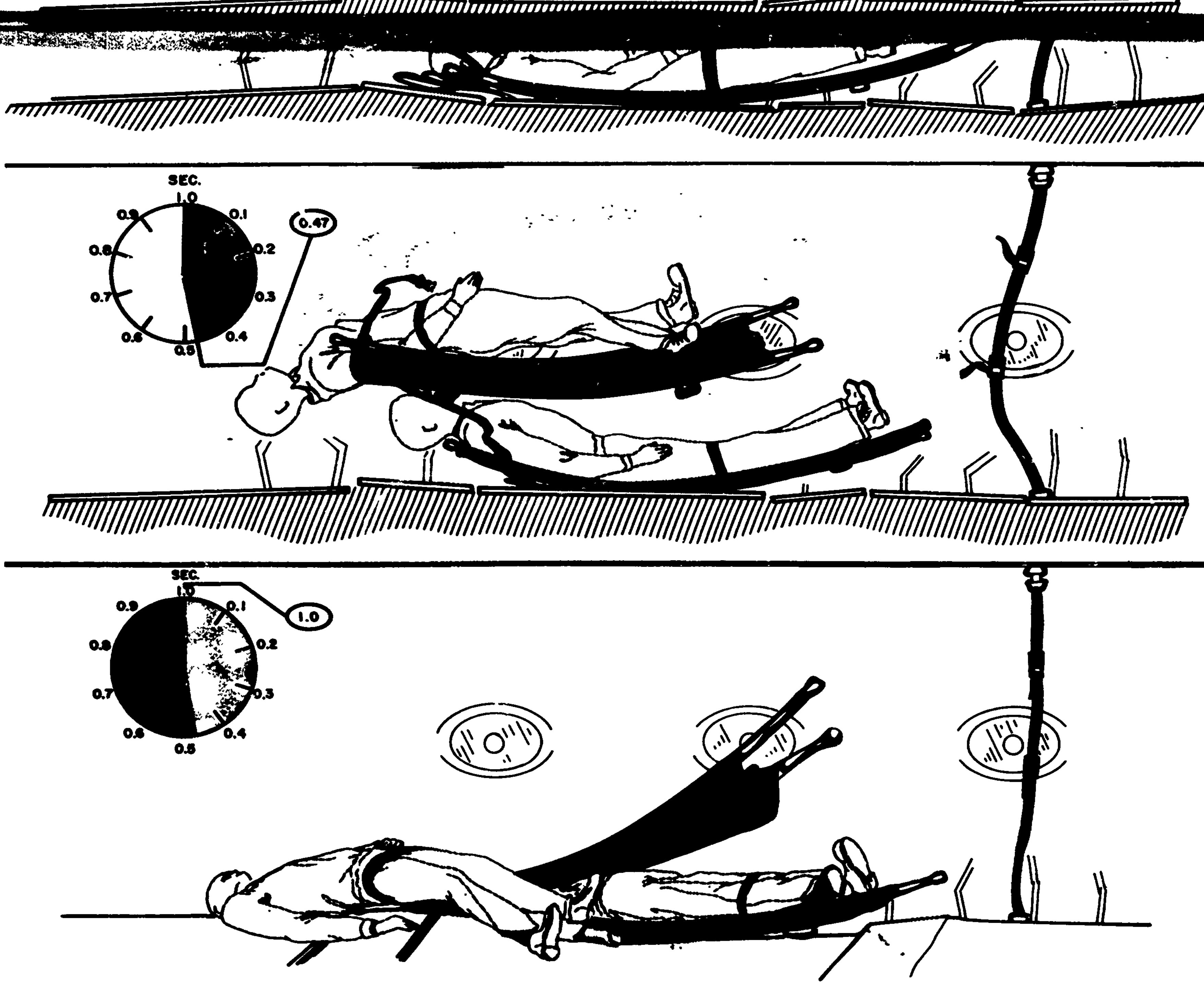

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Figure 3. Kinematics of CH-21 Litter System Failure.

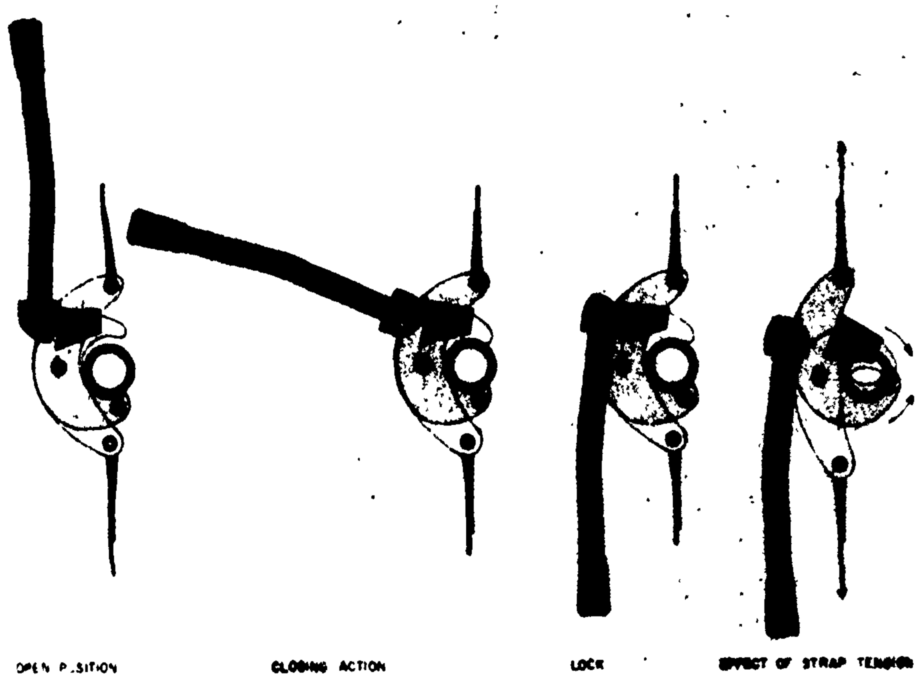

Figure 4. Experimental Attachment Fitting.

Figure 5. Postcrash View of Standard UH-1D System (Modified).

1. Magnitude of the accelerating force
2. Rate of application (onset in G/second)
3. Duration of force
4. Direction in which force is applied to the body
5. Body restraint during acceleration

The actual crash force phenomenon is determined by the first four parameters, while the fifth, body restraint, constitutes the opposing force. For this reason, the type of restraint is generally considered the primary variable in human tolerance to impact acceleration.

Although such has not always been the case, the trend in the design of aircraft occupant retention systems has been toward design where human tolerance is given more and more consideration. Figure 6 shows a breakdown of the categories of human tolerance. This is a purely qualitative concept of human tolerance. No numerical values are included because there is a different level of tolerance for each direction of application.

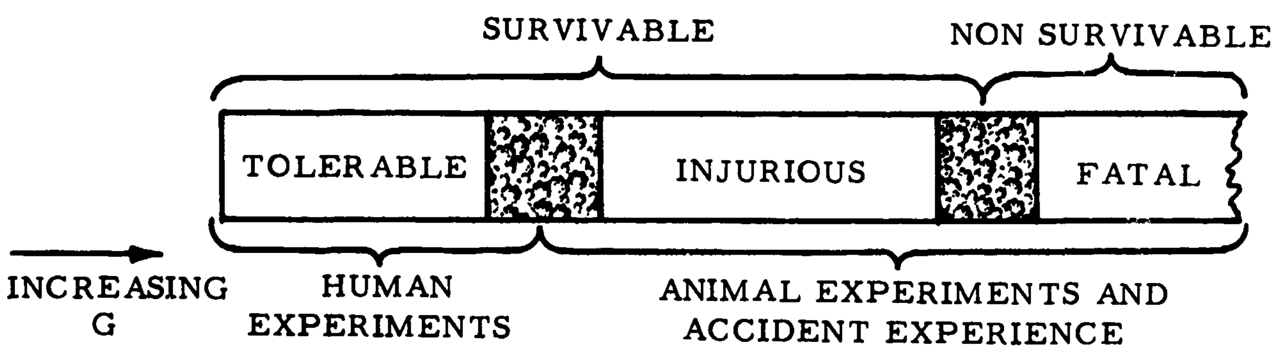

Figure 6. Categories of Tolerance.

These categories can be described as follows:

1. Tolerable Limits: These are the acceleration limits set by voluntary subjects in experimental work and as deduced from accident experience.

   The subject is not incapacitated, although minor trauma, including abrasions, etc., not requiring immediate medical care, is acceptable if it does not significantly impede the subject's escape from the crashed aircraft.

2. Injurious Limits: These are associated with moderate or severe trauma and/or incapacitation, but with survival insured with prompt medical care. The subject may be unable to extricate himself from the wreckage in time to avoid death by fire, drowning, or other postcrash hazards.

3. <u>Fatal Limits:</u> These are based on nonsurvivable trauma as a direct or indirect result of excessive force application upon the body.

As pointed out in References 7 and 8, the recommended strength requirements for an occupant restraint system should be set well beyond the known tolerable limits, where the limits of human tolerance in a particular axis would be exceeded before the restraint system failed. It is generally preferable to accept some degree of injury due to the forces of acceleration than to have the restraint system fail and the occupant receive contact injuries by impacting against aircraft structure.

In the case of aeromedical litters, however, the theoretical human tolerance could be so high as to render designing to this human tolerance value impractical. With the litter patient in the supine postion, he is actually in an optimum position for tolerating vertical loads (with respect to the aircraft). These vertical loads are dominant in helicopter-type accidents.

Literature on the subject of human tolerance to impact acceleration indicates that the direction of force application and the area of force distributions on the human body are important influencing factors regarding tolerance (Reference 4). Tolerance to acceleration acting perpendicular to the spine (a_x) is considerably higher than acceleration acting parallel (a_z) to the spine. The reasons for this are as follows:

1. The skeletal configuration and mass distribution of the human body are such that loads resulting from vertical accelerations (on a seated occupant) cannot be as readily distributed over a restraint system as can loads resulting from transverse accelerations. Therefore, vertical loads on the seated occupant generally result in a greater stress per unit area than transverse loads.

2. The viscera have more freedom of movement (displacement) in the vertical plane or long axis of the body than in the horizontal plane. Consequently, accelerations acting parallel to the spine cause more strain on the suspension system of the viscera than equivalent accelerations acting perpendicular to the spine.

The variation in human G tolerance with respect to body orientation is best demonstrated by a comparison of ejection-seat and free-fall experience. It is generally accepted that, for minor or no injury, the tolerance to headward acceleration ($+a_z$) for a properly seated and restrained subject is 20-25G acting for periods up to 0.1 second. In a

study of free-fall accidents (Reference 5), it was concluded that the human body has withstood an estimated 200G for very short intervals during which the force ($+a_x$) acted perpendicular to the long axis of the body (subject landed in soft dirt in a supine position). This so-called miraculous survival in free-fall accidents demonstrates the body's high tolerance to transverse acceleration ($+a_x$) when the area of force distribution is maximized and the impinging surface yields (in plastic deformation) sufficiently.

Table I shows some typical force distributions with various impinging surface areas. The figures are based upon a 10G acceleration and a body weight of 170 pounds.

TABLE I
TYPICAL SEAT BELT FORCE DISTRIBUTIONS DURING 10G ACCELERATIONS

	Approximate Contact Area (sq in.)	Approximate Load (psi)
2-inch seat belt	40	42.0
3-inch seat belt	60	28.0
Aft-facing seat	210	8.0
Litter	500	3.4

It can be seen that the greater the contact area between the body and impinging surface, the smaller the force per unit area. In the case of litters, it will be noted that the approximate load per unit area is only 3.4 psi.

In all of the research on human tolerance in which live human subjects were used, it has been determined that when adequately restrained, the body is capable of withstanding the highest magnitude of force when the direction of the force is perpendicular (a_x) to the spine and the sign is positive ($+a_x$ - "eyeballs in").

Reference 6 cites the case of a human subject who sustained 83G for 0.04 second's duration. In this particular case, the subject was exposed to the acceleration ($+a_x$) while seated upright in an aft-facing seat. It should be mentioned, however, that this exposure can hardly be considered "tolerable" because the subject was sufficiently debilitated that he could not have effected his own escape. The case is mentioned only to

show that such exposure was endured and that the subject survived with no permanent injuries.

Another example of high $+a_x$ tolerance where the area of force distribution was maximized was in the case of space capsule research, where human subjects lying supine in molded couches endured $+a_x$ forces as high as 126G for short durations.

It can be inferred from the foregoing that an occupant oriented in the supine position on an aeromedical litter is in the best possible position from the human tolerance point of view insofar as vertical crash forces on the aircraft are concerned.

LITTER SYSTEM DESIGN STRENGTH CRITERIA

Based on research that has been conducted on human tolerance to accelerative force in the $+a_x$ axis-"eyeballs in", it can be safely assumed that the tolerable limit for a suitably restrained occupant to vertical crash forces while lying supine on a litter is in excess of 50G, for short-duration (millisecond) pulses. However, it is neither practical nor desirable to design litter systems to this 50G value, even though such accelerations are frequently encountered at the floor level in helicopter accidents. The primary reason is that the helicopters in general use today as aeromedical evacuation vehicles are not structurally capable of supporting dynamic loads of this magnitude without extensive modification. The litter systems themselves might be unwieldy and greatly reduce the operational flexibility of aeromedical evacuation vehicles.

For these reasons, the human "tolerable limit" to acceleration in the $+a_x$ axis is not considered to be the controlling factor in aeromedical litter design.

Of more importance are the acceleration data that are associated with typical impacts. Impact data from a series of crash tests of full-scale aircraft conducted by AvSER were used as representative data for investigation. Certain qualitative facts are apparent from the data. First, impact forces in the vertical axis are prevalent in helicopter accidents and will therefore present the greatest threat to the litter occupant. Good retention in the vertical direction in the case of litter systems is particularly important since gross failure due to overloads in this direction can have catastrophic results.

Longitudinal accelerations recorded at the floor level in helicopters are less of a problem except where the impact may occur at high forward velocity, and statistically this does not often occur. The AvSER crash tests indicate that attenuation of the high-amplitude short-duration

longitudinal accelerations occurring at the floor is effected through the intervening structure between the floor and the occupant. Table II shows the attenuation effect on longitudinal accelerations on a variety of occupant retention systems in one representative crash test.

This table demonstrates that the presence of very short-duration high-longitudinal loads recorded at the floor level does not have a direct effect on the longitudinal loads recorded at the pelvic areas of suitably restrained anthropomorphic dummies.

TABLE II
LONGITUDINAL ACCELERATION PEAKS IN A TYPICAL CRASH

Measurement	Peak Value (G)	Remarks
Cockpit floor	175	
Pilot pelvic	30	
Passenger cabin floor	75	
Commercial passenger seat dummy (pelvis)	30	Forward facing; restrained by seat belt only
Experimental troop seat (dummy)	25	Suspended from ceiling
Experimental troop seat (dummy)	22	Supported at the floor

Lateral loads have never reached significant levels in the AvSER test series because of the controlled orientation of the aircraft at impact. In any event, it is believed that the lateral accelerations would seldom be greater than the longitudinal accelerations usually occurring in survivable longitudinal impacts.

The problem is predominately one of reducing to practical values the vertical accelerations imposed upon the litter and hence the inertia loads imposed upon the litter support system and the airframe structure.

This can most easily be accomplished by allowing relative displacement (via "energy absorbers" or "load limiters") of the litter with respect to the aircraft floor. In order to bring about an understanding of the order of magnitude of these relative displacements, the following analysis was made.

1. The triangular acceleration-time plot of Figure 7 is assumed as a typical "input" to the litter restraint system at point A of the figure. The energy absorbers are assumed to limit the acceleration of the litter to the trapezoidal pulse also shown in the figure.

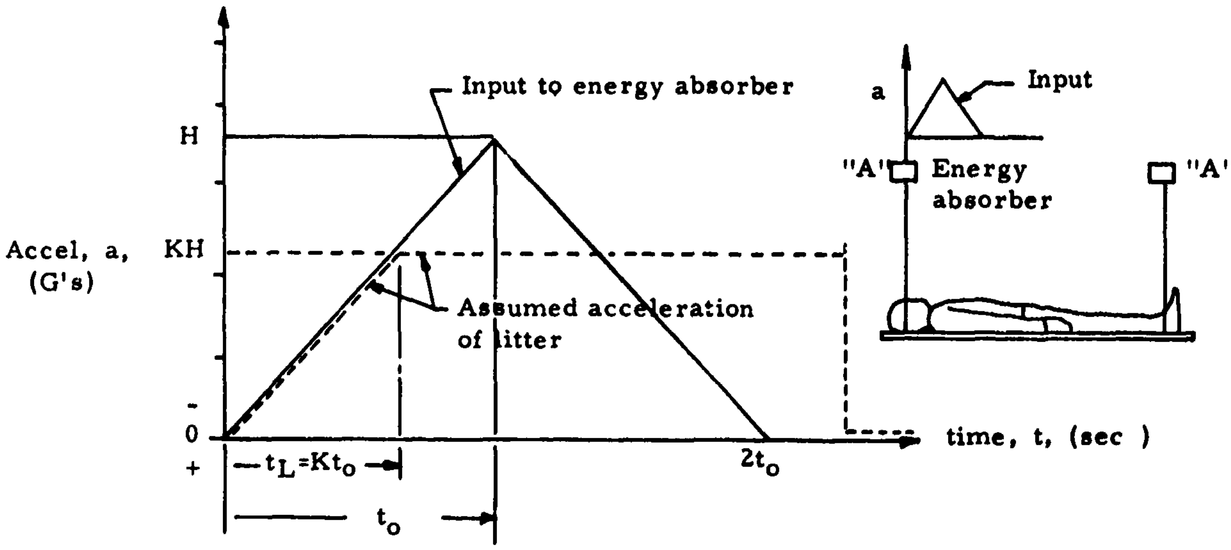

Figure 7. Acceleration-Time Plot Used in the Analysis of the Displacement of the Litter With Respect to the Airframe.

The corresponding velocity-time curves are shown in Figure 8. The relative displacement of the litter with respect to the airframe is equal to the difference in the areas under the velocity curves of Figure 8.

This relative displacement is computed as follows:

Let

H = maximum airframe acceleration - G

$K = \frac{a_L}{H}$ = ratio of limit acceleration to peak acceleration

t_o = one-half the input pulse duration - sec

t = time - sec

a_L = KH = maximum litter acceleration - G

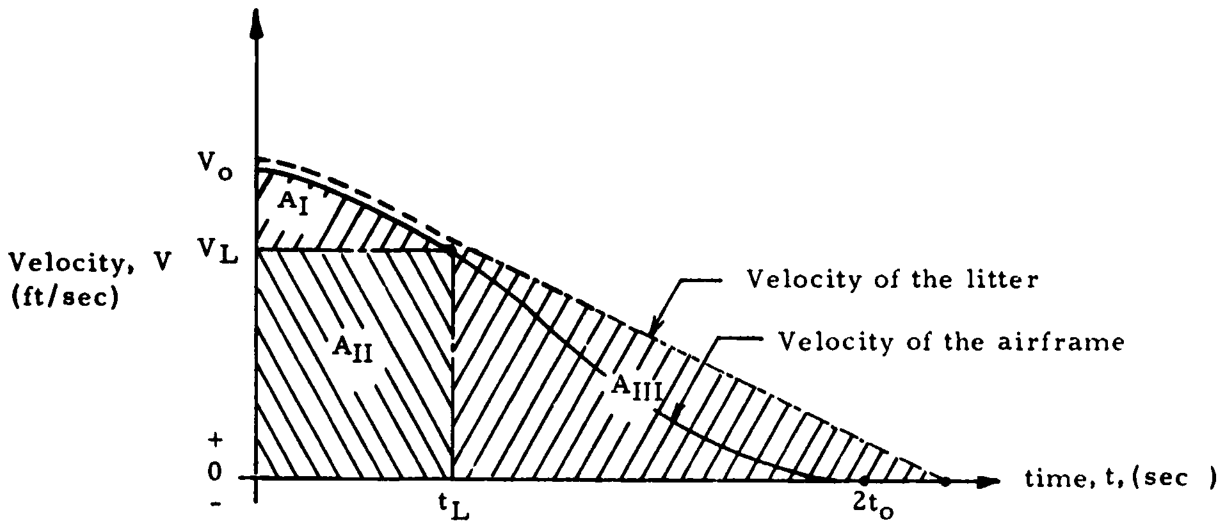

Figure 8. Velocity-Time Curves for the Accelerations of Figure 7.

t_L = time at which the maximum litter acceleration is first reached - sec

$V(t)$ = velocity of the airframe at time "t" - ft/sec

V = velocity - ft/sec

V_o = initial impact velocity - ft/sec

V_L = common velocity of airframe and litter when the maximum acceleration of the litter is first reached - ft/sec

g = acceleration due to gravity - 386 in./sec^2

$a(t)$ = acceleration of the airframe at time "t" - ft/sec^2

S = displacement - ft

Then in the interval $o<t<t_o$,

$$a(t) = \frac{-Hgt}{t_o} . \tag{1}$$

Integrating gives

$$V(t) = -\frac{Hgt^2}{2t_o} + V_o. \tag{2}$$

Also,

$$V_o = Hgt_o. \tag{3}$$

Combining equations (2) and (3) then gives

$$V(t) = \frac{Hg}{2t_o} (2t_o^2 - t^2). \tag{4}$$

The common velocity of the airframe and the litter at time $t_L = Kt_o$ can now be computed from equation (4), giving

$$V_{(t=t_L)} = V_L = Hgt_o - \frac{Hgt_L^2}{2t_o}, \tag{5}$$

and the change in velocity to this time is

$$\Delta V = V_o - V_L = \frac{Hgt_L^2}{2t_o}. \tag{6}$$

The areas A_I and A_{II} can now be computed from geometrical considerations, giving,

$$A_I = 2/3 \text{ base x height} = \frac{2}{3} \frac{Hgt_L^2}{2t_o} \cdot t_L = \frac{Hgt_L^3}{3t_o} \tag{7}$$

$$A_{II} = \text{base x height}$$

$$A_{II} = V_L t_L$$

$$A_{II} = \left[Hgt_o t_L - \frac{Hgt_L^3}{2t_o} \right]. \tag{8}$$

A_{III} can be obtained by applying the equation $A_{III} = S = V_L^2/2a_L$ which is valid for the motion of the litter in the interval $t > t_L$. Thus,

$$A_{III} = \frac{1}{2}\left(Hgt_o - \frac{Hgt_L^2}{2t_o}\right)^2 \cdot \frac{1}{KHg} \cdot \qquad (9)$$

Noting that $K = t_L/t_o$ and solving for the energy-absorber stroke by obtaining the difference of the areas under the velocity-time curves for the litter and the airframe give

$$\text{Stroke} = A_I + A_{II} + A_{III} - \frac{1}{2} V_o (2t_o)$$

$$= Hgt_o^2 \left[-\frac{K^3}{24} + \frac{K}{2} + \frac{1}{2K} - 1 \right]. \qquad (10)$$

As an example, consider a triangular pulse representing a change in velocity of 40 feet per second with

$H = 50G$

$t = 0.025$ sec

$K = 0.4$

The required stroke is then

$$\text{Stroke} = (50)(386)(0.025)^2 \left[-\frac{0.4^3}{24} + \frac{0.4}{2} + \frac{1}{2(0.4)} - 1 \right]$$

$$= 5.44 \text{ inches}$$

2. A similar study utilizing a sinusoidal input gives, for the required stroke,

$$\text{Stroke} = \frac{2Hgt_o^2}{\pi^2} \left[\frac{1 + \cos\frac{\pi K}{2}}{\sin\frac{\pi K}{2}} \right] - \pi(2-K) + 2 \sin \frac{\pi K}{2} . \qquad (11)$$

Equations (10) and (11) were evaluated by computer for peak accelerations up to 150G and time durations up to 0.10 second.

The results of these computations are plotted in Figures 9 and 10.

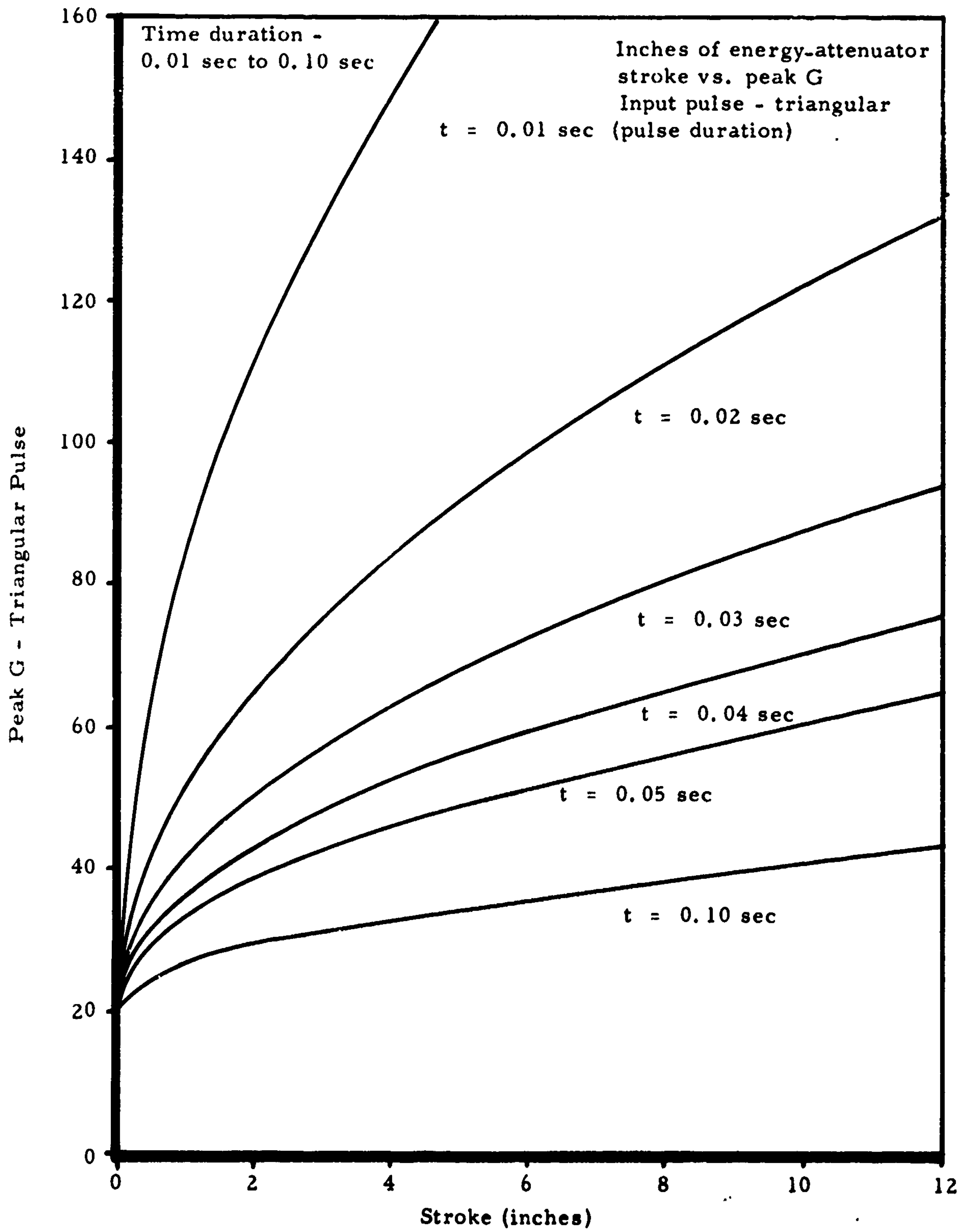

Figure 9. Stroke vs. Peak G for Triangular Pulse.

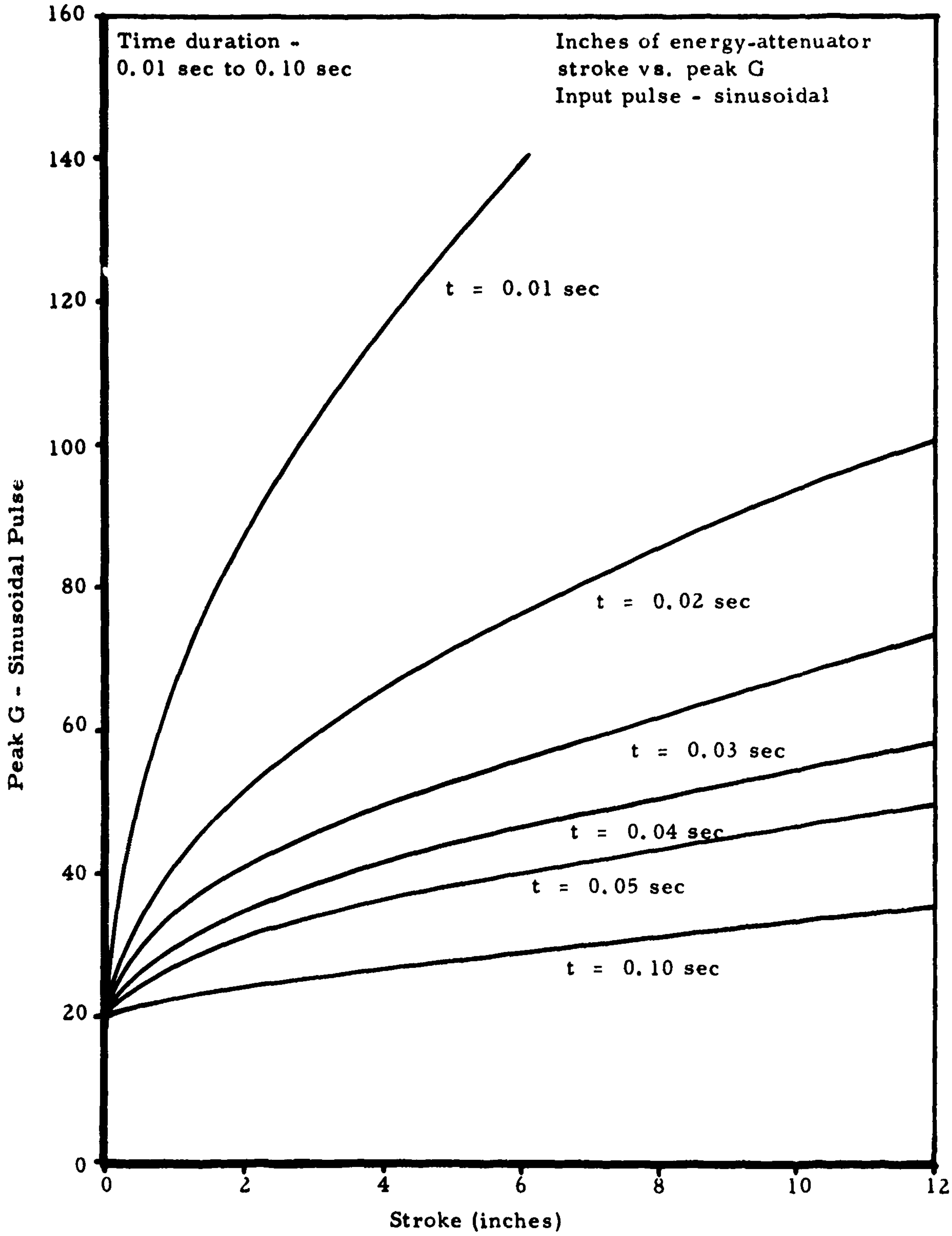

Figure 10. Stroke vs. Peak G for Sinusoidal Pulse.

Data from dynamic crash tests show that sinusoidal pulses are associated with long-duration, low-G situations where high-G peaks which are predominant in helicopter accidents are more generally triangular in shape. When an acceleration-time history indicates that a superimposed peak is present, the stroke length required in such a case can be closely approximated by superposition as in Figure 11.

1.	Stroke due to sine wave	5.2 in.
2.	Stroke due to triangular peak	0.4 in.
3.	Total stroke length required	5.6 in.

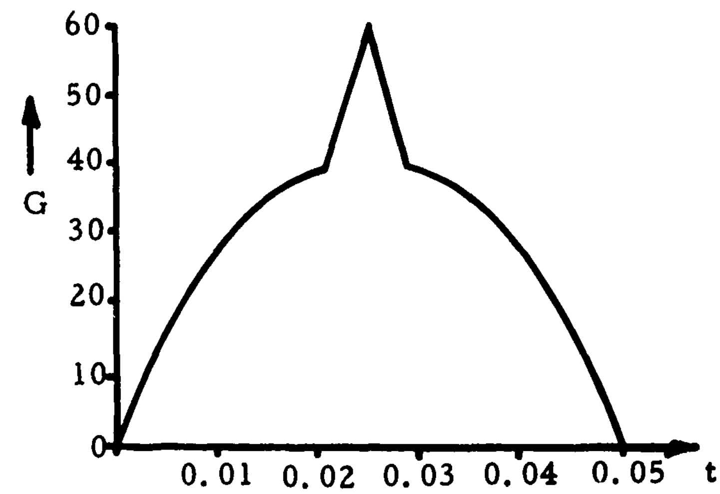

Figure 11. Sine Wave With Superposed Peak.

Acceleration-time histories from AvSER full-scale dynamic tests were analyzed, and the stroke lengths required for various values of limiting G were calculated. Twenty G, the target limiting G value, was chosen as representing a G level well within the human tolerance spectrum while allowing sufficient attenuation for occupant protection in known survivable accidents.

The vertical accelerations measured at the floor of the test helicopters were used as the input data for evaluating the survivability potential of a theoretical crashworthy litter system. This is a conservative approach because floor vertical accelerations in helicopter accidents are generally much higher than those recorded at the ceiling structure where the litters would be suspended. In all cases evaluated, the energy-attenuation stroke required to maintain 20G on the litter occupants was less than 9 inches. Because the litters themselves bend under load, it is desirable that at least 12 inches of vertical stroke be provided. This means that the standard practice of placing the lowest litter of a stack on or near the floor is a practice which makes litter occupant injuries likely in moderate to severe accidents.

In the longitudinal or lateral direction, a value of 25G is desirable as an overall system strength sufficient to provide protection in severe but potentially survivable accidents. This G value assumes a litter system completely occupied by patients of the maximum weight expected. The 25G must be maintained during the entire acceleration pulse and in combination with the vertical acceleration. This means that the actual strength requirements of a particular component must be better than 30G.

The majority of the present-day helicopters could not structurally support a litter system built to the above criteria without some modification. Nevertheless the development of aeromedical evacuation vehicles which afford reasonable crash survival potential will require the structural capacity for litter systems built to the above specifications.

The existing standard litter system was examined thoroughly to determine if minor modifications could be incorporated to raise the vertical load-carrying capability to 20G. It was determined that the maximum capability that could be achieved in the litter poles was 18G. This could be accomplished by moving the litter attachment brackets from a 75-inch spacing to a 46-inch spacing on the litter pole. The maximum capability of the litter bed, however, was only 15.7G.

In view of the fact that these strengths were significantly below the strengths required for a crashworthy system, an experimental litter system was developed. This system incorporated all of the recommendations from former litter tests as well as the above criteria. The details of the litter design are shown in Appendix II. The litter system was not intended to be a prototype but rather an experimental research tool to evaluate the problems involved in the design of a crashworthy litter retention system. Various changes from the specifications for present-day litter systems were incorporated. They included reducing the span between litter supports to reduce the bending moment of the litter poles. The litter poles were strengthened by a change in material specification, and the moment of inertia was raised to provide a pole of sufficient strength and stiffness to meet the requirements for crashworthiness. Positive restraint in the longitudinal and lateral direction was incorporated to eliminate the failure due to longitudinal or lateral loads noted in previous litter tests.

The concept of altering the span between the litter brackets is worthy of special comment. All aeromedical evacuation vehicles are presently designed to accept a litter suspended at a 75-inch spacing. With a litter that can be held at any point along the litter pole, the aircraft designer then has the design freedom to locate the litter tiedown points at an advantageous position relative to aircraft strength capabilities. It is

shown in Appendix II that the strength of standard litters can be doubled by restraining the litters at a 46-inch spacing. The closer to this 46-inch spacing that can be achieved in the aircraft, the greater the strength potential of the litter. With a litter pole such as suggested in Appendix II, the litter brackets can be placed at any point on the span of the litter pole.

The experimental litter system was evaluated by a series of dynamic tests. First, a series of drop tower tests was conducted to determine the actual strength of the litter system in a single-axis test. The tests showed that the system was capable of loads of over 24G before structural failure occurred. The litter system was then installed in an XH-40 helicopter which had been modified to accept an overhead-mounted litter system. Load limiters (energy absorbers) were installed in each litter strap to limit the litter acceleration to 20G.*

The XH-40 was dropped from a moving crane with impact parameters of 44 feet per second forward and 40 feet per second downward. The litter system did not function as planned owing to failure to the forward litter straps at the stitching. Certain conclusions can be drawn from the test, however, which demonstrate even more the need for the development of a crashworthy aeromedical evacuation system. The litters failed at a G level of approximately 20G. The standard litter system previously failed at approximately 9G. This means that a system of more than twice the strength of the standard litter system still fails with catastrophic results in a potentially survivable crash.

The problem of proper stitching of strap material for use in dynamic situations is shown to be one of the most important problems in the design of a crashworthy litter system. The same straps (1-inch by 0.10-inch Dacron strap - strength 5600 pounds) which came unstitched in this test at approximately 2450 pounds had previously been tested at load values significantly higher than 2450 pounds. In the single-axis drop-tower tests, the straps had been subjected to 3000 pounds without failure. In a series of static tests on a universal testing machine, the straps failed at loads in excess of 4000 pounds.

Despite the fact that the litter strap stitching failed under dynamic loading in the XH-40 crash tests, there was ample reason to believe that an aeromedical litter system capable of withstanding impact loads in excess

*The load limiters used functioned by pulling soft wire through a series of severe bends. The actual device is described in USAAML Technical Report 65-30.

of 20G vertically and 25G longitudinally and laterally was feasible. Such a system could be constructed simply without a significant weight increase over standard systems.

It was also apparent from the test that critical components such as litter straps (including stitching) and support brackets should be designed with an ample safety factor above static test strength to preclude failure under dynamic crash impact loading. It is not entirely within the state of the art to predict dynamic behavior of structure on the basis of static testing. However, in view of the insignificant weight involved in the case of litter components such as support straps and brackets, a safety factor of approximately two to one is not considered to be prohibitive.

CONCLUSIONS

Based on the foregoing, it is concluded that:

1. Aeromedical litter systems designed to MIL-A-8865(ASG) fail under moderate impact conditions.

2. Existing aeromedical litters will fail under vertical dynamic loading at approximately 7.5G. With proper adjustment of the support bracket location toward the center of the litter to reduce bending moments, a loading of approximately 18G can be sustained on the litter poles. The canvas litter bed, however, is capable of withstanding only approximately 15G. This latter value therefore becomes the limiting factor; and, although it represents a 100-percent improvement over existing litters, it is still considered to be inadequate in view of the known threat from crash impact accelerations.

3. In view of a human's relatively high tolerance (50+G) to vertical impact acceleration while lying supine on an aeromedical litter, human tolerance should not be the controlling factor in litter design. If it were, weight and complexity factors would be prohibitive.

4. The controlling factor in aeromedical litter design should be the known acceleration data and structural behavior associated with full-scale aircraft crash tests and typical aircraft accidents.

5. Litter support brackets using the friction principle are not capable of providing the required retention capability between bracket and litter pole during longitudinal loading.

6. Simple load-limiting devices are capable of limiting otherwise destructive loads on aeromedical litters to levels consistent with economical design.

RECOMMENDATIONS

In view of the foregoing conclusions, it is recommended that:

1. Applicable aeromedical litter specifications be revised to provide litter retention when aircraft are exposed to impact accelerations known to occur in severe but potentially survivable accidents.

2. Applicable specifications be based upon the following load factors imposed individually and in combination:

   a. Vertical: 20G measured in the pelvic region of a supine anthropomorphic dummy having the weight and mass distribution of the highest percentile occupant anticipated.

   b. Lateral and Longitudinal: 25G + 5G for 0.10 second measured in the pelvic region of a supine dummy having the weight and mass distribution of the highest percentile occupant anticipated.

3. In order to maintain a vertical load of 20G, simple load-limiting devices be used that will allow deformation through at least 12 inches of travel.

4. A positive lock between support brackets and litter poles be incorporated to increase litter retention during longitudinal impact loading.

5. Litter bed material be changed from canvas to a material capable of supporting the heaviest occupant expected during vertical crash impact accelerations in excess of 20G.

6. In order to reduce bending moments in litter poles during vertical impact loading, support bracket spacing be reduced from 75 inches to approximately 60 inches, and the strength of the pole material be increased by using 2024-T4 or 7075-T6 aluminum alloy to increase the ultimate failure load of the pole by 50 percent or more.

7. If certain critical litter components such as support straps and support brackets are to be statically tested, a safety strength factor of approximately two to one be considered to preclude failure during dynamic loading.

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APPENDIX I

DYNAMIC TEST OF A STANDARD LITTER SYSTEM FOR UH-1D HELICOPTER

DESCRIPTION OF THE TEST ARTICLE

The test article consisted of a litter system made up of standard UH-1D components installed in a CH-21 helicopter for the crash test. The test installation included one stack of three litters as installed on the right side of the UH-1D.

In the UH-1D, the litters are supported on one side by rigid attachment to a bulkhead or stanchion and are suspended on the other side by straps attached to the ceiling and floor of the aircraft. The left side installation of this system in a UH-1D helicopter is shown in Figure 12. The vertical distance between the floor and the ceiling of the UH-1D is approximately 57 inches.

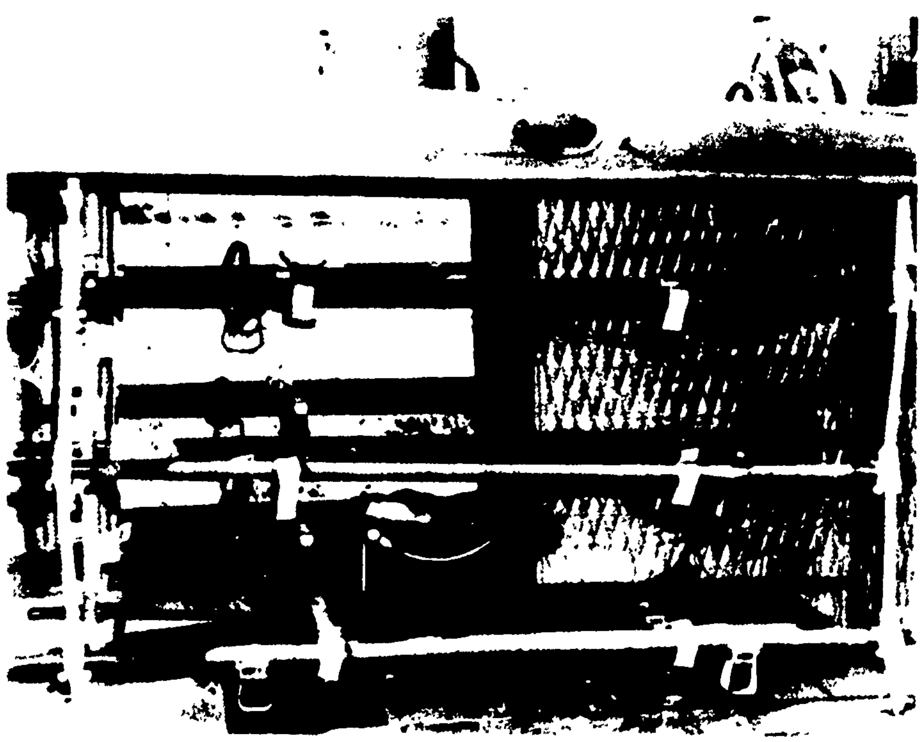


Figure 12. Standard Litter Installation in UH-1D Helicopter.

The litter stack was installed between fuselage stations 120 and 220 in the forward passenger compartment of the CH-21 used for this test, with the rigid supports outboard and the strap supports inboard. The height of the test installation was held at 57 inches by building a

supporting structure into the top of the CH-21 cargo compartment, 57 inches above the floor. A sketch of the installation is shown in Figure 13.

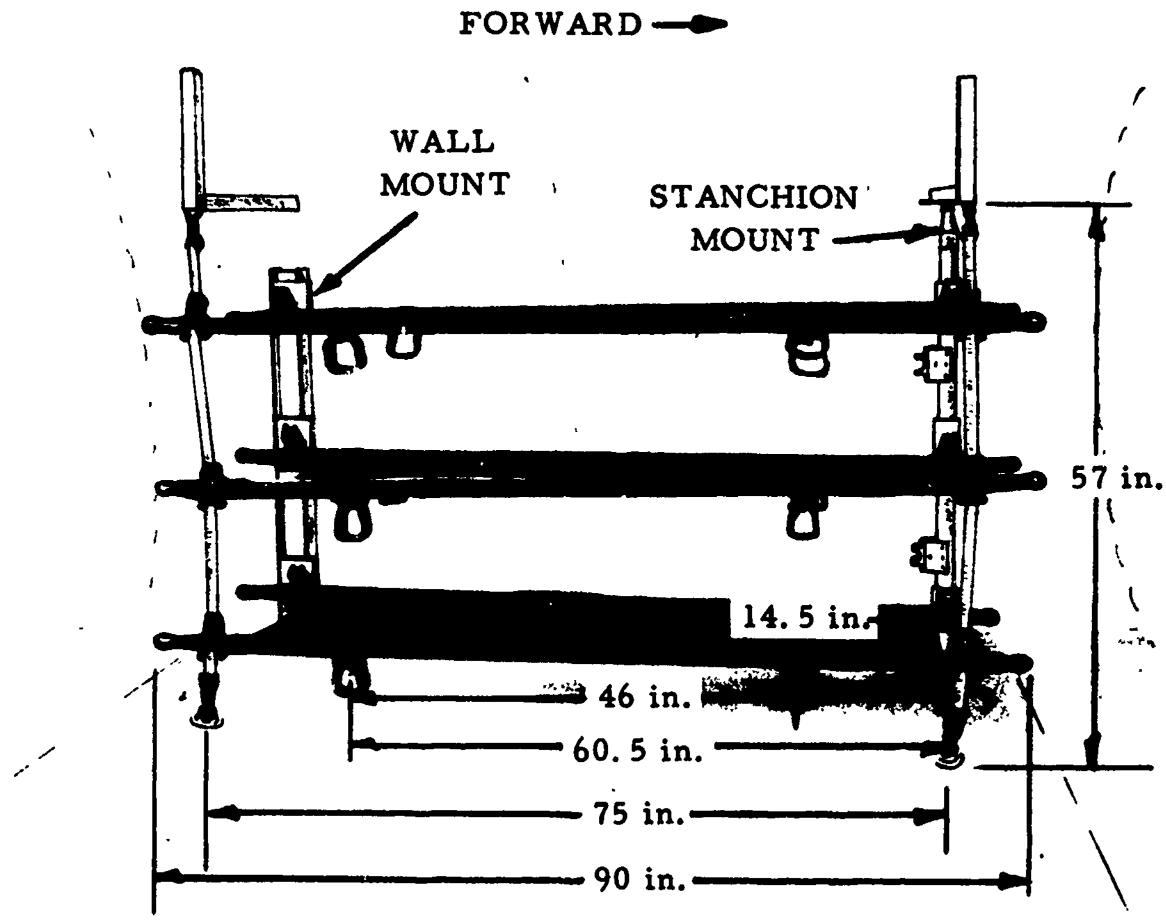


Figure 13. UH-1D Litter Installation in CH-21A Helicopter.

The litters that were used in this system were standard, rigid, aluminum-pole, folding litters, as specified in Military Medical Supply Agency Drawing No. 20017 (Federal Stock Number 65307837905) manufactured in accord with MIL-L-16462A, 30 June 1960.

The upper and center litters carried anthropomorphic dummies, while the lower litter carried a canvas sandbag dummy with a lengthwise distribution of weight similar to normal human weight distribution. The placement of the anthropomorphic dummies and the sandbag dummy is shown in Figure 14.

Information on individual dummy weight and restraint methods is given in Table III.

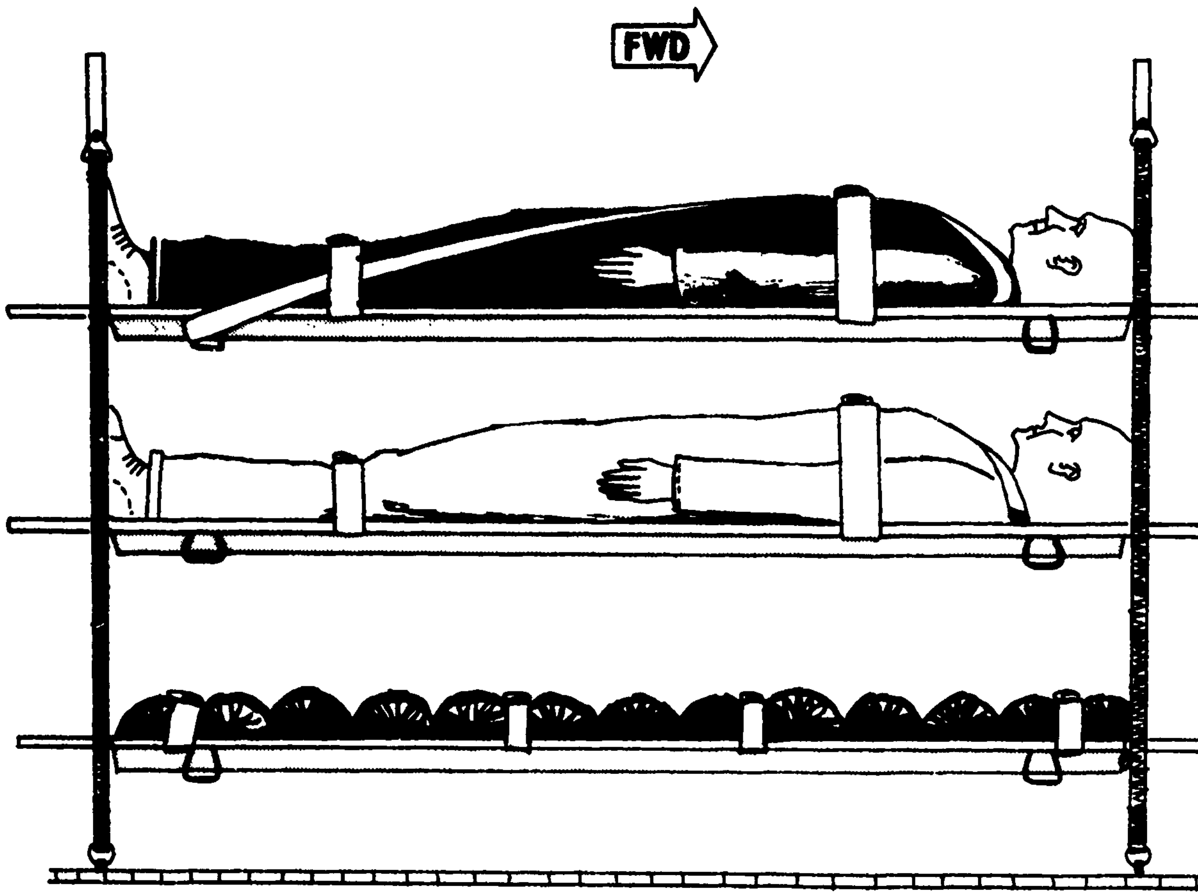


Figure 14. Dummy Placement on Litters in CH-21A Test Helicopter.

TABLE III
EXPERIMENT WEIGHT AND RESTRAINT INFORMATION

Dummy	Dummy Weight (lb)	Restraint Method	Weight of Restraint Method (lb)	Litter Weight (lb)	Total Weight (lb)
Upper	185	Harness	8	15	208
Center	200	Two straps	5	15	220
Lower (Sandbag Simulation)	207	Four straps	10	15	232
	592		23	45	660

The instrumentation system provided time histories of the vertical and longitudinal accelerations encountered in the pelvic region of the top

anthropomorphic dummy and also the tension loads in both litter support straps. The vertical, longitudinal, and lateral accelerations of the passenger cabin floor near the litter installation were also recorded.

TEST RESULTS

The test vehicle was crashed onto an asphalt runway from a maximum height of 111 feet above the ground. At impact, vertical velocity of the helicopter was 52.5 feet per second and horizontal velocity was 66.0 feet per second. These conditions resulted in a velocity of 89.3 feet per second along a 38-degree flight path. This combination of conditions produced a severe crash as shown in Figure 15, resulting in structural damage which varied in severity along the inhabitable length of the fuselage as shown in Figure 16.

Figure 15. Postcrash Condition of Test Helicopter.

In the cockpit, at the one extreme, volume was reduced to such an extent that the crash was nonsurvivable in that area. The aft passenger cabin, at the other extreme from the standpoint of damage severity, was definitely survivable, since in this area little structural collapse occurred above the floor of the helicopter.

Between the cockpit and the rear of the passenger cabin, there was a definite increase in survivability from front to back, and all of the passenger cabin was probably survivable. (This assessment of survivability

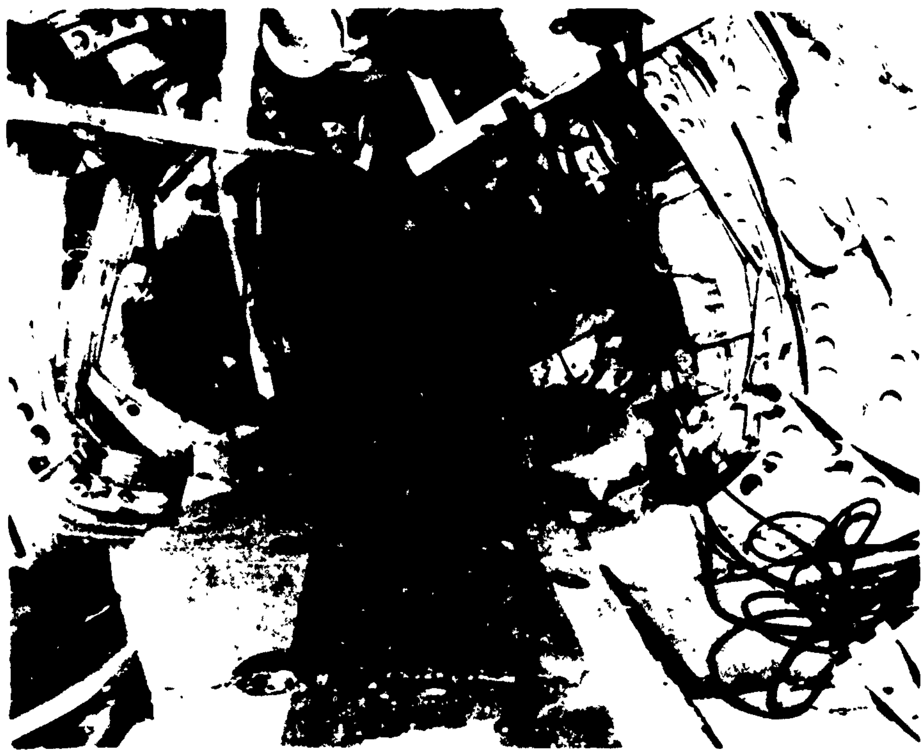


Figure 16. Postcrash Overall Damage to Helicopter Interior. (View looking forward with experiments removed.)

is made on the basis of fuselage collapse only; the acceleration levels produced by this crash exceeded human tolerance and would not have been survivable in some sections of the aircraft without adequate energy-absorbing systems.)

In the area of the litter installation, fuselage stations 120 to 220, crash forces reduced the fuselage height to 58.25 inches at the forward litter support and to 59.75 inches at the aft litter support. The total height of the fuselage was reduced to an average value of approximately 59 inches in the litter installation area. These postcrash measurements may have been somewhat less during impact, but study of high-speed film footage does not indicate a significant degree of elastic deformation.

Of the 59 inches of postcrash vertical space, approximately 6 inches was occupied by structure below the floor line and approximately 15 inches was taken up by the structure built into the upper fuselage to support the litters. This left only 38 inches of vertical space for the litter system which originally occupied 57 inches.

The overall effect of this vertical collapse of the fuselage structure during the crash was to lower the roof and the whole litter system toward the

floor. The bottom litter and dummy contacted the floor and were subjected to nonsurvivable acceleration levels. This condition is portrayed in Figure 17.

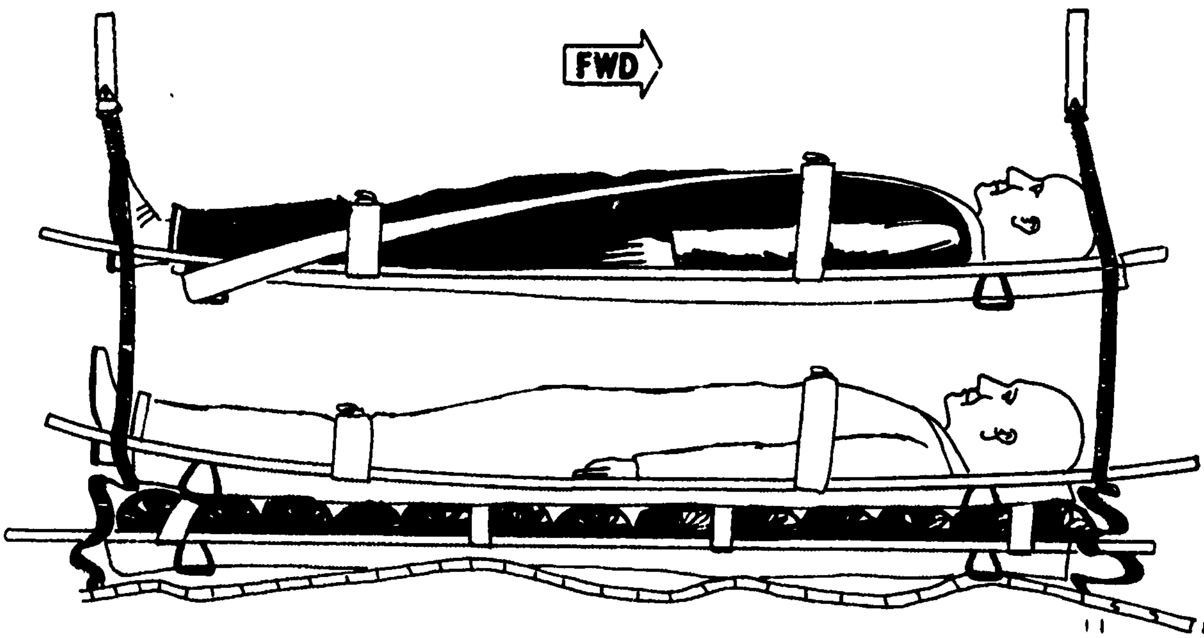


Figure 17. Lower and Center Dummy/Litter Contact.

As the collapse continued, the middle litter and dummy impacted the lower dummy with resultant high accelerations imposed on the center litter dummy. The action continued until the top litter and dummy contacted the center dummy. The total effect is shown in Figure 18.

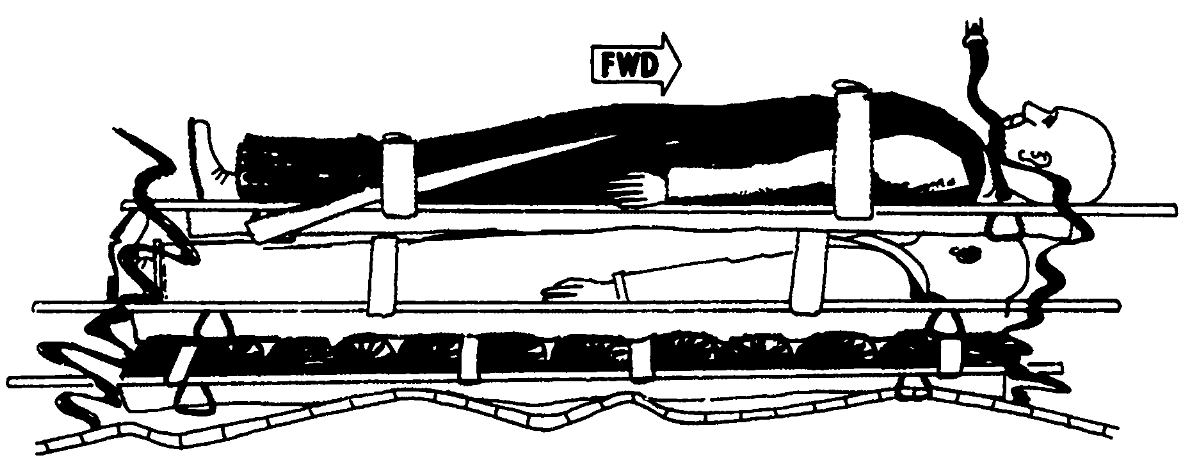


Figure 18. Progressive Impact on All Three Dummies.

Although the lower and center dummies may have provided some cushioning for the dummy above them, the overall high accelerations and successive load transfers experienced throughout the litter system created

a crash environment of lethal conditions. Figure 19 is a sketch showing the entire system and dummies in the final position.

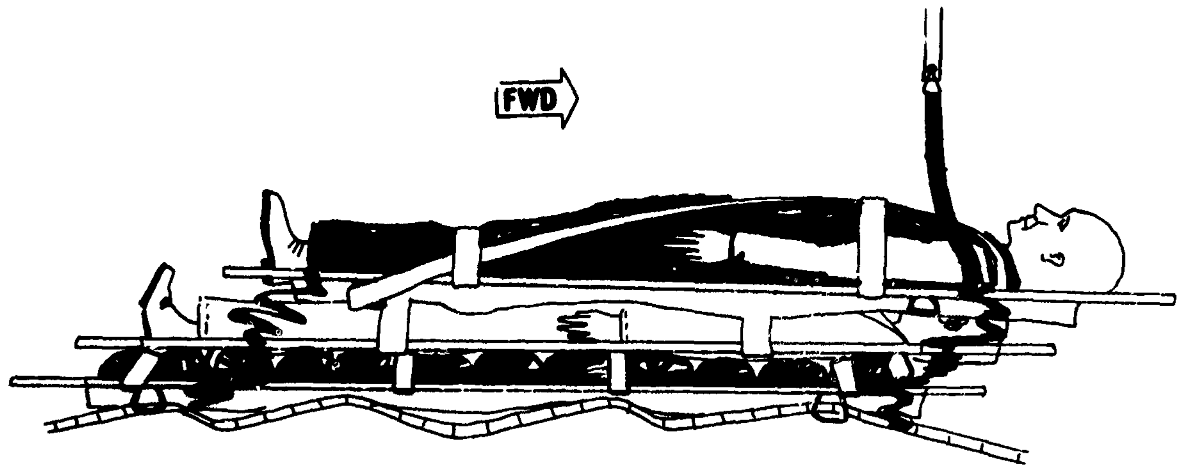


Figure 19. Final Position of Litters and Dummies.

All three litter positions were subjected to acceleration levels and crash conditions which would have been fatal to human occupants. In addition, severe injuries could have resulted from the litter stirrups and spreader bars as they contacted the middle and lower patients (dummies) during the collapse of the system.

The severity of the impact is evidenced by the high acceleration levels recorded in the pelvic region of the upper litter dummy. Peak readings are stated below.

Direction	Recording
Longitudinal	83G peak with 25G maintained for over 8 milliseconds
Vertical	135G peak with 50G maintained for over 11 milliseconds

The effects of the test crash on the major components of the litter system are summarized below and discussed in detail later in the text.

Component	Damage and Performance Summary
1. Pole Brackets	
a. Stanchion Mounted (Forward End)	Upper bracket broke, and center and lower brackets deformed. All brackets opened and released litter poles.

	b. Wall Mounted (Aft End)	Lip on upper bracket broke, center bracket did not deform, and lower bracket bent forward. All brackets opened and released litter poles.
	c. Strap Mounted (Fore and Aft)	No significant damage was incurred by any of the six brackets. Five retained hold on litter poles; one (top aft) was freed. Upper and center brackets slipped downward on straps.
2.	Litter Poles	
	a. Bottom	Rigid side pole received 1/4-inch permanent deformation and strap side pole 1-3/4-inch permanent deformation.
	b. Center	Rigid side pole broke, and strap side pole deformed 1-7/8 inches.
	c. Upper	Rigid side pole received 9-5/8-inch permanent deformation and strap side pole 1/2-inch deformation.
3.	Strap Supports	
	a. Forward	No visible damage; became detached from floor connection.
	b. Aft	No visible damage; became detached from overhead connection.
4.	Stanchion Mount, Forward	No significant damage; bottom came loose.
5.	Wall Mount, Aft	No significant damage; remained attached to fuselage in installed position.
6.	Webbing	Stitching on upper litter sustained one 15-inch rip. Several punctures were caused by local contact with other objects, not by general overloading.

Further effect of the movement of the roof structure toward the floor was the release of longitudinal restraint on the strap side of the litters.

This produced sudden longitudinal overloading of the litter support brackets that were attached to the stanchion and basic aircraft structure. These brackets were designed primarily to resist vertical loads, and when subjected to the combined vertical and longitudinal loading encountered in the test crash, the brackets failed and released the litter poles. Details of the damage sustained by the brackets are reported below.

Stanchion-Mounted Brackets (Forward End of Litter Installation)

The upper bracket shown in Figure 20 failed owing to combined forward and downward loading. The lower aft side broke, and the lower forward side bent forward and downward. This failure resulted in the complete release of litter restraint in this location.

Figure 20. Upper Bracket, Stanchion Mount.

The center bracket shown in Figure 21 twisted forward but did not break. The twisting released the clasp and prevented positive retention of the litter pole. Signs of extremely high vertical loading were not evidenced, probably owing to the fact that the center litter and dummy were in contact with the lower litter and dummy before any extreme deformation occurred.

The lower bracket is shown in Figure 22. Full vertical loading of this bracket never developed because the litter and dummy bottomed on the aircraft floor very early in the crash sequence. As a result, it was the least damaged of the three stanchion brackets, sustaining only a slight

forward bend from longitudinal loading. The clasp of this bracket released, however, and the litter pole was unrestrained.

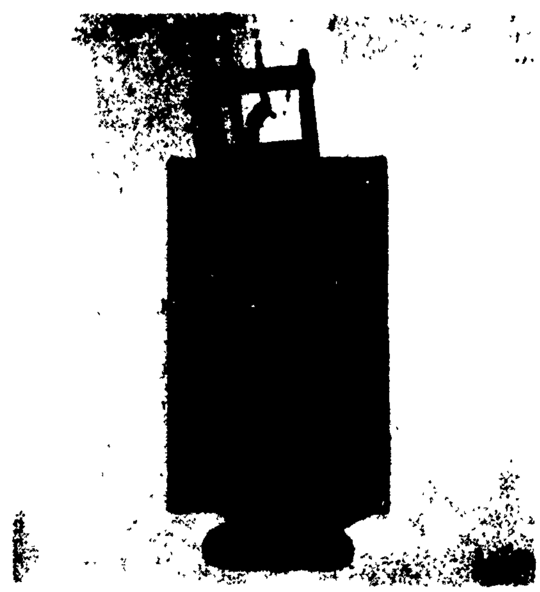


Figure 21. Center Bracket, Stanchion Mount.

Figure 22. Lower Bracket, Stanchion Mount.

Since all three brackets failed to retain the litter poles, the stanchion itself evidenced no damage. Further, there is no indication of failure on the part of the bracket-to-stanchion attachments.

Wall-Mounted Brackets (Aft End of Litter Installation)

The forward lip of the upper bracket, shown in Figure 23, broke. However, the remainder of the bracket was not appreciably deformed. The clasp was open at the end of the crash and did not retain the litter pole, although scar marks on the pole handles indicate that the clasp remained closed for part of the crash.

Figure 23. Upper Bracket, Wall Mount.

The center bracket shown in Figure 24 was not permanently deformed in the crash. Scrape marks indicate that the litter pole pulled out of the bracket while the clasp was closed, although the clasp was found in the open position during the postcrash investigation.

The lower bracket is shown in Figure 25. The mounting pad to which this bracket was attached was sheared away by upward load caused by contact with a longitudinal stringer below the floor. Before this occurred, however, the forward side of the clamp was bent forward. The litter pole shows a short scrape terminated by an indentation. The indentation probably was caused by the upward load which caused failure of the mounting pad.

The overall failure pattern of the litter installation can be termed a "family" of weak links in a chain that includes tiedown features, bracket hardware, and litter pole deformation.

The weak link in the tiedown chain was longitudinal restraint. This weakness brought on the failure of the solidly mounted litter support

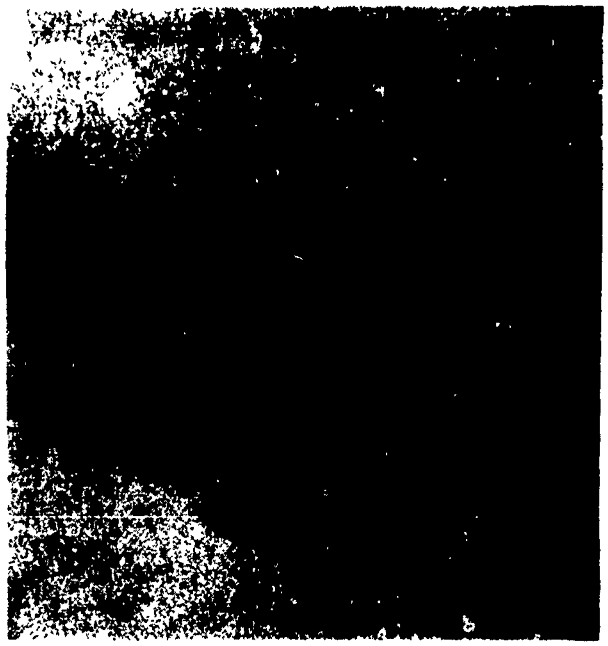


Figure 24. Center Bracket, Wall Mount.

Figure 25. Lower Bracket, Wall Mount.

brackets that has been covered in preceding text and photographs. The loss of vertical restraint at the bracket support points is directly related to the longitudinal forces imposed.

The severity of the accelerations involved is evidenced by the postcrash condition and position of the three litters. Figures 26, 27, and 28 are photographs presented in reverse order from the sequence in which

Figure 26. Bottom Litter, Postcrash.

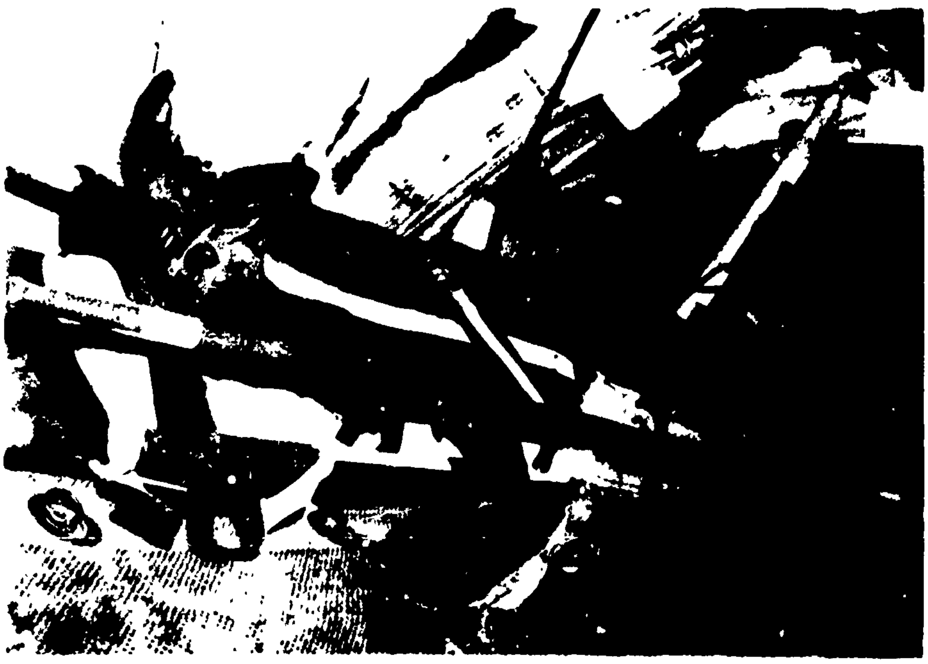


Figure 27. Center Litter, Postcrash.

Figure 28. Upper Litter, Postcrash.

they were taken so that the reader can best realize the dynamics involved when:

1. The lower litter (Figure 26), which was in contact with the floor structure virtually throughout the crash, moved forward 14 inches after the brackets released. This movement occurred while the force of the center and upper litter loads was being imposed upon the lower litter. Deformation of the litter poles was slight, owing to the upward contact with the floor, resulting in a 1/4-inch permanent deformation on the wall side and a 1-3/4-inch deformation on the strap or aisle side.

2. The center litter (Figure 27) moved forward a total of 25 inches - 11 inches farther than the bottom litter. The solidly mounted pole on the wall side of this litter was loaded to its ultimate capacity during this movement and broke at the forward stirrup bolt hole. Deformation measuring 1-7/8 inches was recorded on the aisle side.

3. The upper litter (Figure 28) moved 36 inches forward from its original position. The structure-mounted litter pole on the wall side received a permanent deformation of 9-5/8 inches at a point 42 inches from the end of the forward litter handle,

while the strap-mounted pole deformation measured only 1/2 inch at a point 40 inches from the forward handle end.

Strap-Mounted Brackets

None of the strap-mounted litter support brackets were damaged by excessive loads. The lower, forward floor-strap connection and the aft, top roof-strap connection were both disconnected during the crash. Neither of the attaching clips showed any sign of overloading or impact damage, and both of the releases are unexplained.

Both upper brackets slipped downward on the straps: 9 inches on the forward one and 2 inches at the rear. The center forward bracket slipped downward along the strap approximately 9 inches, while the center aft bracket slipped approximately 2 inches. Neither of the bottom strap-mounted brackets moved downward on the straps. The lack of movement would be expected since the bottom litter was loaded from below by the aircraft floor.

None of the forward brackets were displaced along the litter poles. The upper aft bracket was free of the litter pole, the center aft bracket slipped rearward approximately 1/8 inch, and the lower aft bracket was not displaced.

The extreme movement and severe effect presented above are considered the result of loss of restraint on the litter poles that was caused by the bracket failures. Maximum use of the energy-absorbing potential of the litter poles was not realized as a result of the longitudinal movement.

On each of the three litters, the poles on the structure side were more severely deformed than those supported by the straps. This was due to the difference between the rigid support offered by the structure-mounted brackets prior to their failure and the slippage which occurred between the strap-mounted brackets and the straps, as well as the loss of support which occurred when the aft strap was released from its upper support.

There were several punctures of the litter webbing, and the stitching on the forward strap-mounted side of the top litter was ripped from the forward edge aft for 15 inches. These tears and rips were probably caused by local contact with other objects and not by general overloading of the webbing.

DISCUSSION OF TEST RESULTS

The impact conditions in this test (approximately 53 knots along a 38-degree flight path) produced a severe but partially survivable crash. The crash was designed to produce an environment which bordered on the upper limits of survivability with helicopter-type structure.

The CH-21 aircraft structure does not simulate UH-1D structure in its response to dynamic crash loading. However, under similar crash conditions, vertical accelerations at the floor level of the UH-1D would be equal to or greater than the accelerations encountered in this test. Also, it may be expected that when UH-1D helicopters are involved in crashes of equivalent severity, there will be a reduction of vertical space similar to the reduction from 57 inches to 38 inches which occurred in this CH-21 test. The preceding statements are theoretical, however; there is still no actual data available for comparison. The UH-1A has been shown to be deficient in retention of living space in severe accidents as shown in Figure 29.

Figure 29. Postcrash Damage to a UH-1A Helicopter. (Reduction in vertical space in the occupiable area is shown.)

An XH-40 helicopter was crash tested after the CH-21 was modified with the addition of a steel tube roll bar. This was for the twofold purpose of (1) simulating structural changes in UH-1B and UH-1D

helicopters and (2) providing a structural member for overhead support of a litter system. Even with the roll bar structure,the occupiable area between the litter supports was reduced from 52 inches to 39 inches. This fact agrees with the theoretical analysis used in installing the UH-1D litter system in a CH-21.

Two weaknesses in the litter system were apparent from this test. One was the vulnerability of the lower litter patient to contact with the floor; the other was the lack of adequate litter retention, particularly in the longitudinal direction.

The vulnerability of the bottom litter patient is a straightforward problem. The bottom litter is located too close to the floor to be crashworthy. This is illustrated in Figure 12, showing the bottom of the litter stirrups' having only 3 inches of floor clearance. This small clearance assures that the bottom litter occupant will contact the floor in marginal impacts, even those in which the litter system remains intact.

A partial solution to this problem, from the standpoint of crashworthiness and human tolerance, is to reduce the number of litters in the stack to two, eliminating the bottom litter. If this were done, the litter nearer the floor would then have a 20-inch clearance. Although this litter might still contact the floor in a severe crash, the amount of energy remaining by this time would be small and the injury resulting from the contact would be reduced to a minimum (assuming, of course, that the litter system does not fail structurally). From an operational point of view, it is recognized that elimination of this one litter would significantly reduce the productivity of an operational helicopter, and is therefore probably not acceptable. The alternate solution is to load the bottom litter last and only when necessary.

The second obvious weakness in the UH-1D litter system is the variation in rigidity of support created by the use of rigid stanchions and straps which can stretch. The brackets attached to the rigid stanchions must provide the restraint for the entire system during the early part of the crash pulse, until the strap-mounted supports have reached their stretch limit and begin to carry an appreciable load. This overloads the rigidly mounted brackets, causing premature failure, which can lead to complete retention system failure due to progressive failure of system components.

This situation would be improved by providing identical restraint at all four support locations. This could be accomplished by using straps or cables at all suspension points, with suitable lateral and longitudinal restraint.

The two weaknesses cited above affect the overall design concept of the UH-1D litter retention system. There are detail components of the system which also need improvement.

The clips which attach the litter support straps to the aircraft roof and floor are not positive. The floor attachment clip is shown in Figure 30.

Two of these attachments were released in this test, although there was no indication of excessive loading in any of the clips. Failure of any one of these clips results in considerable loss of retention and directly increases the load which must be carried by the rest of the system. These clips should positively attach the straps to aircraft structure.

Figure 30. Floor Attachment Clip.

The litter support brackets are poorly designed for transmitting longitudinal loads. Litter retention in the longitudinal axis is provided by friction between the litter poles and the rubber grips of the litter support brackets. The gripping force available, and thus the friction force, is limited by the use of the rubber gripping pads and the action of the

adjustable overcenter locking clasp, which is hand actuated. This arrangement is not adequate for suspension of the system when longitudinal loads are applied, but it could easily be augmented with a shear-pin type device which would positively lock the litter pole to the bracket.

Several of the rigidly mounted bracket locking clasps were released because:

1. Rotational forces were applied in a horizontal plane when the litter poles loaded the brackets because of horizontal forces.

2. Rotational forces were applied in a vertical plane when the litter poles bent because of vertical forces.

3. Rotational forces were applied in a lateral plane because of the unsymmetrical loading of the total support system - rigid poles on one side and flexible webbing on the other.

4. The design of the brackets was inadequate.

Solution of this problem might be achieved with a gimbal-type fitting between brackets and attachment points. Stability during normal operation could be achieved with a shear-pin arrangement and a totally flexible system.

A final detail deficiency of these rigidly mounted support brackets lies in the manner in which they are attached to the structure and stanchions. For each bracket, four stud bolts are used which fit into four keyhole slots. Adequate vertical and longitudinal strength may be provided by this arrangement, but twisting of the brackets is caused by the litter poles' bending under load. This action in itself causes deformation and failure of the brackets. This problem could be reduced or eliminated through the use of one centrally located stud bolt to carry the loads and a small shear pin (fuse pin) to provide stability to keep the bracket aligned in normal use. If this method were used, the bending of the litter poles could be used to absorb energy, and failure of the brackets would not be forced by twisting.

APPENDIX II

DEVELOPMENT OF THE AvSER EXPERIMENTAL LITTER

DESIGN OBJECTIVES

The AvSER experimental litter was designed to achieve a strength capability as high as possible while retaining the same weight and size characteristics of existing litter systems. To accomplish the objective, certain fundamental changes were incorporated in the litter design. These changes were as follows:

1. The strength of the litter pole was increased by changing from one type of aluminum alloy to a type of different specifications.

2. The bending moments in the litter poles were reduced by changing bracket spacing on the litter poles from 75 inches to 60 inches.

3. The gripping brackets were modified to incorporate a positive tie between the litter pole and the bracket.

4. The eccentric loads previously experienced on the litter brackets were reduced by the use of straps at all four tie points rather than a combination of straps, stanchions, and wall points.

5. The litter system was positively restrained in the lateral and longitudinal directions by means of a tongue-and-groove device attached to the basic aircraft structure. This device allowed free movement of the litter in the vertical direction.

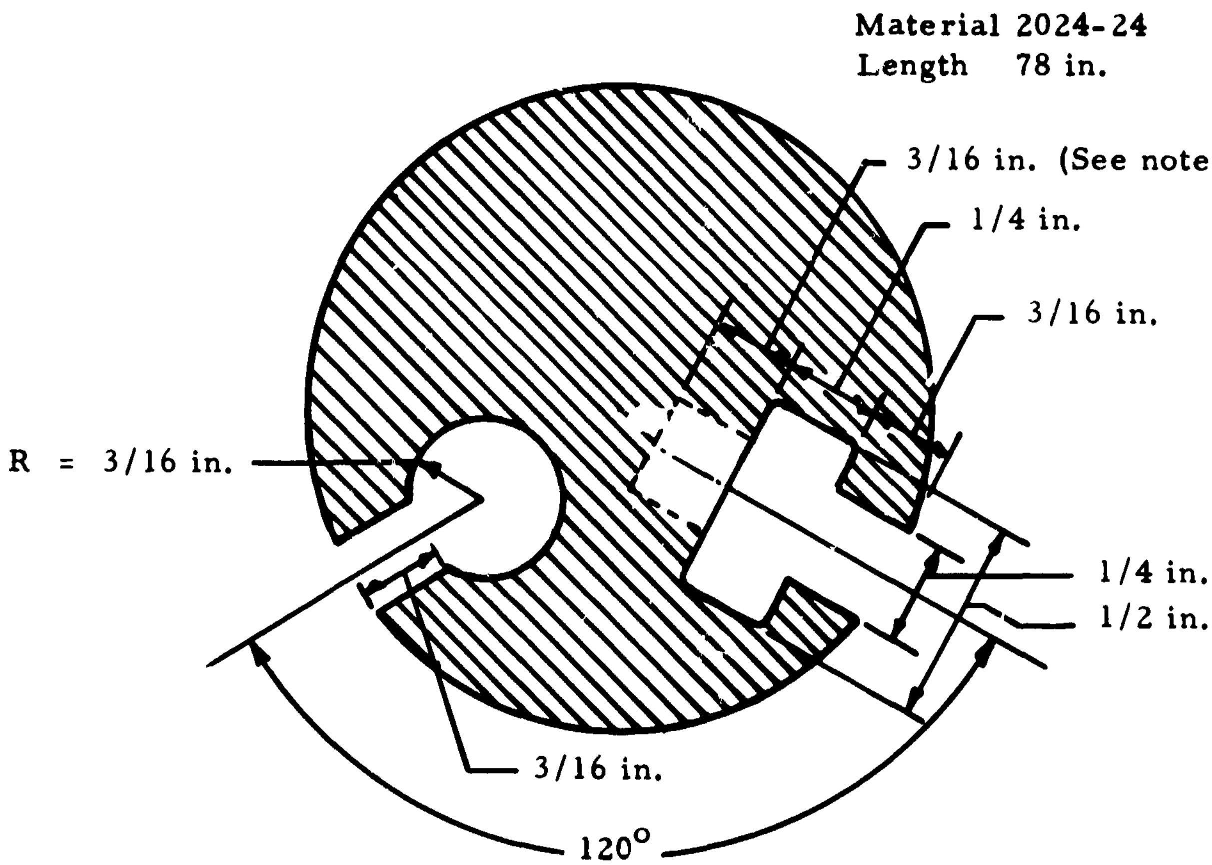
6. The litter bed of canvas was replaced with a nylon net material of higher strength.

DESIGN DETAILS

Litter Poles

The litter poles were machined from a 1-1/2-inch-diameter 2024-T4 aluminum bar. Figure 31 shows the design specifications for the litter pole.

The slot for attachment of the litter bracket permits attachment at any point on the litter pole. This is accomplished by drilling a 1/4-inch-diameter hole to accept the litter bracket pin. This feature is considered



Note: 1/4-in.-diameter hole drilled at desired litter strap spacing

Figure 31. Litter Pole Specifications.

desirable because it allows an increase in design flexibility. Litters can be designed to fit the aircraft. The existing design incorporating a fixed envelope size does not permit this flexibility.

The litter bed is secured to the litter pole by sewing the edge of the bed around a rod 1/4 inch in diameter. The rod is then inserted along the length of the groove, permitting a full-length attachment between bed and pole. This method of attachment leaves the bracket attachment slot clear along the full length of the litter pole. Attachment can then be made at any point. Existing litter beds are sewn around the entire litter pole, thus limiting attachment to the pole ends only.

The weight of the solid aluminum bar is 13.8 pounds. The machining of the grooves as shown in Figure 31 reduces this weight to 12.0 pounds. For use in a production system, it is anticipated that this tube would

be extruded, thereby greatly reducing the weight. If a wall thickness of 0.20 inch were used, the weight could be reduced to 9.0 pounds per pole. If the wall thickness were further reduced to 0.12 inch, the weight of the poles would be the same as poles presently being used. Even at this weight, the strength would be greater than that of existing poles.

The following strength analysis of the standard litter pole demonstrates the need for a pole having greater strength than those currently in use. The allowable vertical G load on the standard litter pole is determined by the resisting moment which can be developed in the poles. This moment is approximately 18000 inch-pounds (9000 inch-pounds per pole).

The loading of litters as specified in MIL-L-16462A produces a maximum bending moment located at the center of the beam. This moment is equal to approximately 12P inch-pounds where P is the maximum applied load.

Assuming a 200-pound litter occupant, the maximum allowable G loading for the litter system would be

$$18000 \text{ inch-pounds} = 12P$$

$$\frac{P}{200} = \text{number of G}$$

$$G = \frac{18000}{(12)(200)} = 7.5G$$

This loading of 7.5G represents the maximum vertical strength of the litter in its present form, attached to bracket supports 75 inches apart.

Using the same litter poles but moving the bracket supports toward the center to the location of stirrups (46 inches on existing litters), the maximum bending moment still occurs at the center of the beam but at an approximate value of only 5 times the maximum applied load as opposed to 12 times with the wider spacing.

The maximum allowable load under this configuration would then be

$$M_{max} = 18000 \text{ inch-pounds} = 5P \text{ inch-pounds}$$

$$\frac{P}{200} = \text{number of G}$$

$$G = \frac{18000}{(5)(200)} = 18G$$

This value represents a substantial gain in the theoretical strength of the litter poles, but it is still not adequate to resist realistic vertical crash loads. To bring the poles up to desired strength, 2024-T4 aluminum alloy was used. The use of this alloy would permit a maximum allowable vertical load of 27G with poles of the same size as those presently in use if they were supported by brackets at the stirrup locations (approximately 46 inches apart). In order to approximate more closely the bending of an extruded litter pole, the test series was conducted with a bracket spacing of 60 inches.

Litter Pole Gripping Device (Brackets)

All standard litter brackets use the friction principle to hold the litter pole in place during longitudinal and lateral loading. Previous research indicated that because of a low coefficient of friction between the brackets and litter poles, the litters would not remain secured when exposed to longitudinal and lateral loads. In an attempt to solve this problem, litter brackets incorporating a higher coefficient of friction between bracket and pole were developed. These brackets also failed to remain secured when exposed to dynamic test loads. It was apparent that a bracket incorporating a positive lock between bracket and pole was required. Such a bracket was developed and is shown in Figure 32.

The principles of operation of the positive-lock litter bracket are as follows:

1. The litter pole is slipped in the bracket while the locking pin flange (see arrow in Figure 32) is rotated parallel to the slot in the pole.

2. The hole in the litter pole slot and the nipple end of the locking pin are aligned, and the pin is seated in the hole.

3. The locking pin is then rotated 90 degrees by means of a lever arm and is secured in place by the locking lever, thus effecting a positive lock between litter pole and bracket.

Litter Straps

The litter straps were made of Dacron* to reduce the stretching that is characteristic of nylon straps. The straps were 1 inch wide and 0.10 inch thick with a static breaking strength of 5600 pounds. It was anticipated, however, that this strength would be significantly reduced when

*Registered T. M. DuPont.

Figure 32. Litter Bracket With Positive Lock.

one end of this material was looped back on itself, a stitched joint made, and then tested statically.

Selection of a proper thread type and stitching pattern was investigated, with no optimum obtained. The use of a Dacron cord with a static breaking strength of 35 pounds and a three-point cross-stitch pattern was found to give a static breaking efficiency of 80 percent, or approximately 4500 pounds, as compared to the 5600-pound breaking strength of the unstitched strap. This stitched joint proved to be the most critical aspect during developmental testing.

Under dynamic loading conditions, however, the strength reached under static test conditions was not achieved. It is desirable, therefore, that a design safety factor of sufficient magnitude to allow for anticipated dynamic effects be incorporated in the litter straps.

Lateral and Longitudinal Restraint Device

In order to maintain the litter in its proper plane, tongue-and-groove devices were incorporated in the litter brackets on one side of the litter. It was intended that these devices would maintain the litters in their proper lateral and longitudinal positions while allowing vertical movement for the energy-attenuation system.

It is anticipated that some lateral and longitudinal restraint device will be required in any energy attenuating system. Without such a device, slack from an energy-attenuated system would allow excessive lateral or longitudinal displacement which could subject the occupants to contact injuries from environmental structure.

Litter Bed

The canvas bed used on a standard litter has a static breaking strength of 15G when occupied by a 95-percentile occupant. This strength is not adequate for vertical accelerations known to occur in many aircraft accidents. In view of this, the standard canvas bed was replaced with a nylon net material capable of withstanding dynamic loads in excess of 30G. The manufacturer of this material guaranteed a strength in excess of 400 pounds per inch. A strength analysis on the standard canvas material indicated that the material itself failed when exposed to a static load of 86.5 pounds per inch. Equivalent G loading upon failure was 15.7G.

DYNAMIC TESTING OF THE EXPERIMENTAL LITTER

An experimental litter was designed in accordance with the criteria developed during this study, and a series of dynamic tests was conducted to confirm the theoretical criteria. The tests were divided into two phases.

In the first phase, a series of tests was conducted with the experimental litter mounted on a test jig and subjected to vertical accelerations of various magnitudes with the use of a drop-tower device. The purpose of this phase was to further refine the design and to determine the structural limits of the litter system.

Seven dynamic tests were performed on the system using the drop tower. After the first few drops, it was discovered that the positive lock to the litter pole still caused eccentric loading of the bracket when dynamic loading caused the litter pole to bend. This problem was overcome by the design and installation of a stronger bracket. Subsequent drops verified the adequacy of the stronger bracket when subjected to eccentric loading.

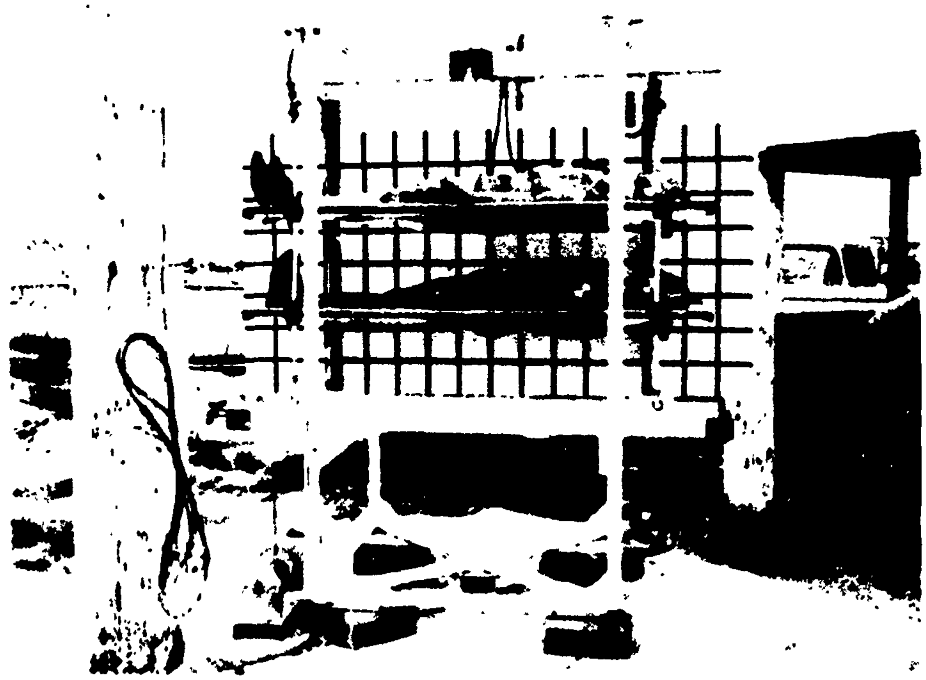


Figure 33. Drop-Tower Testing Device.

Another problem that was raised during the first few drops had to do with the Dacron straps used to support the litters. The Dacron had sufficient strength, but the stitching at the loop joints was not adequate. An attempt was made to find a thread to use in joint stitching that was compatible with the strength of the Dacron itself. As previously mentioned, the 35-pound Dacron cord was found to be acceptable after a test drop where it was used to stitch the strap joints. After these refinements were added, the litter system with a 95-percentile anthropomorphic dummy installed was test dropped at 20G (with both long- and short-duration pulses) without failure. When the acceleration level was raised to 25G, structural failure occurred at the litter brackets. The actual level of failure was at 24.7G. Since the greatest body weight is in the upper torso, the litter brackets failed at the end where the anthropomorphic dummy's head was situated. The brackets at the foot end did not fail, thus allowing some space between the occupied litters. It is considered significant that at no time did the level of acceleration measured at the dummy's pelvis overshoot the peak acceleration measured on the drop-tower test jig.

A computation was made to obtain the energy-absorbing capability of the litter system when limited at 20G. It was determined that a litter retention system that was load limited at 20G would not have failed in several of the previous AvSER full-scale crash tests where vertical impact velocities reached as high as 40 feet per second.

In the second phase of the testing program, the experimental litter system was installed in a modified XH-40 (prototype UH-1) helicopter and subjected to a dynamic crash environment. Load limiters designed to limit vertical acceleration on the occupied litter to 20G were installed. Figure 34 shows the experimental litter system installation in the XH-40 (note arrow pointing to load limiters).

Figure 34. Experimental Litter Installation in XH-40.

The test aircraft, suspended from the boom of a large construction-type crane, was dropped onto an asphalt taxiway at a forward speed of 30 miles per hour. The vertical sink speed on impact was 40 feet per second and the horizontal speed was 44 feet per se‸ond. The aircraft attitude was 10 to 15 degrees nose down with 5 degrees left roll.

Figures 35 through 39 are postcrash views of the XH-40. The roll bar structure was successful in maintaining vertical separation in the occupiable area; however, the action of the transmission contacting the upper rear cross tube of the roll bar structure had a severe parallelogram effort on the structure. This situation was aggravated by the 10- to 15-degree nose-down attitude of the helicopter at impact.

This nose-down attitude resulted in a longitudinal deceleration in the aft fuselage acceleration area, where the litter system was located, of over 60G. This value is in excess of the anticipated longitudinal deceleration level. The rear litter clips were designed to over 25G without yield in all

directions and furthermore were good up to 40G without ultimate failure.

Figure 35. Postcrash XH-40 - Right Side View.

Figure 36. Postcrash XH-40 - Left Side View.

Figure 37. Postcrash XH-40 - Left Front View.

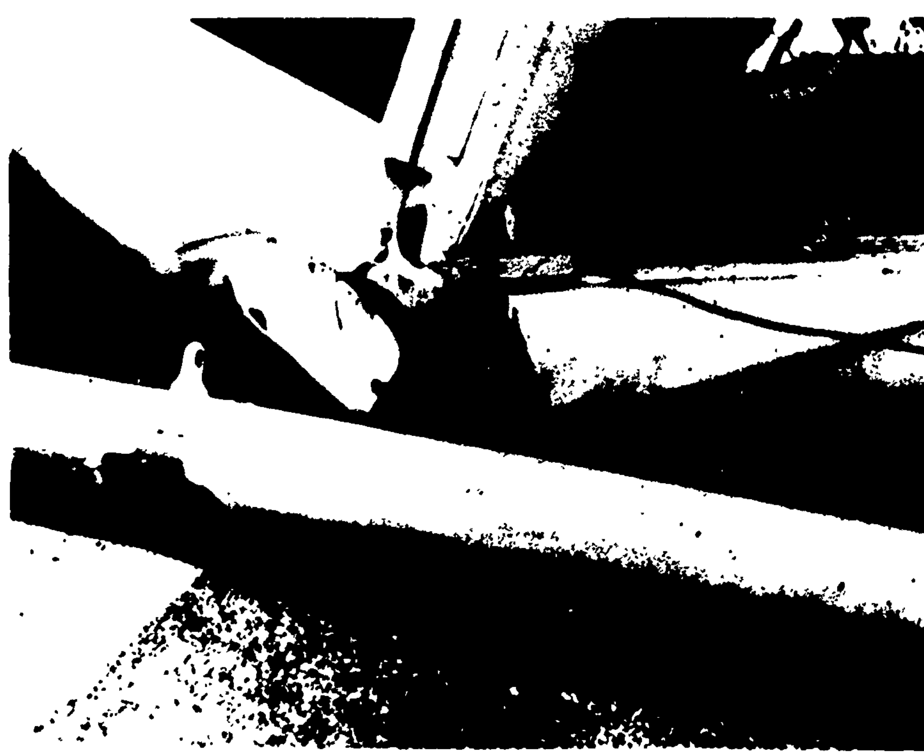


Figure 38. Postcrash XH-40 Fuselage Failure - Right Side.

Figure 39. Postcrash XH-40 Fuselage Failure - Left Side.

It appears that the aft right litter failed in the longitudinal direction, which precipitated the ultimate failure of the litter system.

After failure of the rear litter clips, the litter support straps facing the front of the aircraft (litters were installed with the long axis oriented laterally in the aircraft) loaded up to 22G (2300 pounds) and failed at the litter strap stitching. These same model straps with identical stitching at the joints held the load when tested statically at 4000 pounds and when tested in single-axis (vertical) dynamic tests up to 24.7G. It should be noted here that in these latter test drops, the failure mechanism was due to the litter brackets and not to the litter strap stitching. After the test, the aft litter straps that did not fail were subjected to a static pull. Both straps tested were good for over 4000 pounds before they failed at the stitching.

Despite the fact that the litter system failed under dynamic loading in a full-scale aircraft crash test, it was apparent that simply constructed litter systems capable of withstanding vertical impact loads in excess of 20G were feasible without a significant increase in weight over standard systems. It was also apparent that critical components such as litter straps (including stitching) and support brackets should be designed with an ample safety factor above static test strength to preclude failure under dynamic impact loading. It is not entirely within the state of the

art to predict accurately dynamic behavior on the basis of static testing. However, in view of the insignificant weight involved in the case of critical litter components, a safety factor of approximately two to one at rated load limit value (in this case, 20G) is not considered excessive.

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13. ABSTRACT

Strength requirements of U. S. Army litter/patient retention systems as set forth in current military specifications were analyzed. The analysis was made in light of U. S. Army aircraft accident experience, the human tolerance to abrupt accelerations, and the forces and accelerations that may be anticipated in accidents involving litter-bearing military aircraft. The analysis revealed that the strength requirements quoted in current military specifications are considerably lower than (1) the upper limits of acceleration that can be tolerated by airborne litter occupants and (2) the typical forces and accelerations that are incurred in military aircraft accidents. These conclusions indicated that current litter systems would fail under relatively moderate impact conditions and would thus subject the litter patient to amplified accelerations and increased contact injuries. The existing litter system was analyzed in detail to determine if minor modifications could be made to achieve a vertical load-carrying capability of 20G. Since this strength was not attainable, an experimental litter system designed for a 20G vertical and 25G longitudinal capability was developed.

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